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AMERICAN ELECTRICIANS' HANDBOOK

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AMERICAN ELECTRICIANS' HANDBOOK

A REFERENCE BOOK FOR PRACTICAL ELECTRICAL WORKERS

BY

TERRELL CROFT

CONSULTING ENGINEER

REVISED BY

CLIFFORD C. CARR, E.E., P.E.

HEAD OF DEPARTMENT OF ELECTRICAL ENGINEERING
PRATT INSTITUTE, ASSOCIATE MEMBER A.I.E.E.

SEVENTH EDITION

McGRAW-HILL BOOK COMPANY, INC.

NEW YORK TORONTO LONDON

1953

AMERICAN ELECTRICIANS' HANDBOOK

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Library of Congress Catalog Card Number: 52-10333

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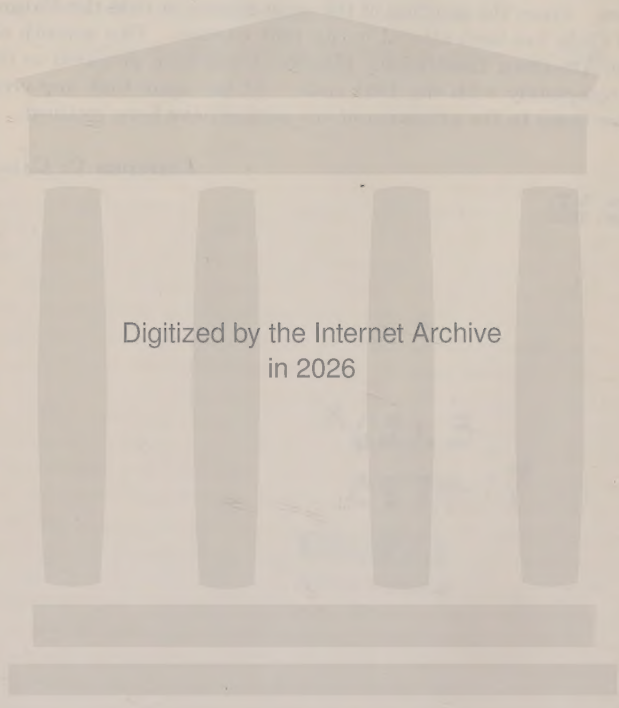
THE MAPLE PRESS COMPANY, YORK, PA.

PREFACE TO THE SEVENTH EDITION

It has always been the aim of the author and publisher of the American Electricians' Handbook to keep the handbook as up to date as possible at all times. Since the printing of the sixth edition in 1948 the National Electrical Code has been altered by its 1951 edition. This seventh edition of the American Electricians' Handbook has been prepared so that it agrees completely with the 1951 code. At the same time any errors which have come to the attention of the author have been rectified.

CLIFFORD C. CARR

BROOKLYN, N.Y.
December, 1952



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PREFACE TO THE FIRST EDITION

This is a practical man's handbook.

In compiling it, the aim has been to collect such information as will enable practical electrical men—wiremen, contractors, linemen, small plant superintendents, operators, and construction engineers—to select and install commercial electrical apparatus and materials intelligently for the performance of given services, and to qualify them for operating the equipment after it has been installed.

For a dozen years the compiler has maintained a personal file of loose-leaf notes on practical electrical subjects. This material constituted the nucleus around which The American Electricians' Handbook has been assembled. Additional matter has been collected from many sources. Extracts from standard books and from technical magazines have been utilized freely. Much of the text is from articles prepared by the compiler and printed in trade papers. The endeavor has been to give proper credit for all material that has appeared previously.

While this is not a so-called "theoretical" book, it is theoretical to the extent that the information that it gives is based on sound physical laws, as all good engineering practice must be. However, the truths arising from the laws have been given rather than the deduction of the laws themselves. Theoretical discussion has been included only where it may be of assistance in enabling the reader to understand why he should do certain things in certain ways.

Some relatively simple subjects have been treated at considerable length, and others of a more complicated nature may, perhaps, appear to have been slighted. There are two reasons for this: *first*, space limitation considerations and, *second*, the desire to cover thoroughly those things which the practical man encounters most frequently.

Illustrations and diagrams, every one of which has been especially prepared for this book, have been used very freely, because one illustration will frequently explain more than several pages of text. Many special problems are solved to indicate the proper application of the rules which are given. No attempt has been made to treat apparatus or materials involving voltages exceeding 2,400.

Although this handbook has been prepared primarily for men of little schooling, it is designed to give practical information on materials, and

suggestions for the selection, installation, and operation of equipment that will be of service to the technically trained engineer.

In books of this character some typographical errors are inevitable. The compiler and publishers will be glad to have notice of any that are discovered, and to have suggestions for the future enlargement and improvement of the book.

TERRELL CROFT

ST. LOUIS, MO.
November, 1913

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USEFUL TABLES

1. Natural Trigonometric Functions

Angle (θ or lag angle), deg.	Sine (or reactive factor)	Cosine (or power factor)	Tangent	Co-tangent	Secant	Cosecant	Angle (θ or lag angle), deg.
0	0.00000	1.00000	0.00000	Infinite	1.0000	Infinite	180
1	0.01774	0.99985	0.01745	57.290	1.0001	57.299	179
2	0.03490	0.99939	0.03492	28.636	1.0006	28.654	178
3	0.05234	0.99863	0.05241	19.081	1.0014	19.107	177
4	0.06976	0.99756	0.06993	14.301	1.0024	14.335	176
5	0.08715	0.99619	0.08749	11.430	1.0038	11.474	175
6	0.10453	0.99452	0.10510	9.5144	1.0055	9.5668	174
7	0.12187	0.99255	0.12278	8.1443	1.0075	8.2055	173
8	0.13917	0.99027	0.14054	7.1154	1.0098	7.1853	172
9	0.15643	0.98769	0.15838	6.3137	1.0125	6.3924	171
10	0.17365	0.98481	0.17633	5.6713	1.0154	5.7588	170
11	0.19081	0.98163	0.19438	5.1445	1.0187	5.2408	169
12	0.20791	0.97815	0.21256	4.7046	1.0223	4.8097	168
13	0.22495	0.97437	0.23087	4.3315	1.0263	4.4454	167
14	0.24192	0.97029	0.24933	4.0108	1.0306	4.1336	166
15	0.25882	0.96592	0.26795	3.7320	1.0353	3.8637	165
16	0.27564	0.96126	0.28674	3.4874	1.0403	3.6279	164
17	0.29237	0.95630	0.30573	3.2708	1.0457	3.4203	163
18	0.30902	0.95106	0.32492	3.0777	1.0515	3.2361	162
19	0.32557	0.94552	0.34433	2.9042	1.0576	3.0715	161
20	0.34203	0.93969	0.36397	2.7475	1.0642	2.9238	160
21	0.35837	0.93358	0.38386	2.6051	1.0711	2.7904	159
22	0.37461	0.92718	0.40403	2.4751	1.0785	2.6695	158
23	0.39073	0.92050	0.42447	2.3558	1.0864	2.5593	157
24	0.40674	0.91354	0.44523	2.2460	1.0946	2.4586	156
25	0.42262	0.90631	0.46631	2.1445	1.1034	2.3662	155
26	0.43837	0.89879	0.48773	2.0503	1.1126	2.2812	154
27	0.45399	0.89101	0.50952	1.9626	1.1223	2.2027	153
28	0.46947	0.88295	0.53171	1.8807	1.1326	2.1300	152
29	0.48481	0.87462	0.55431	1.8040	1.1433	2.0627	151
30	0.50000	0.86603	0.57735	1.7320	1.1547	2.0000	150
31	0.51504	0.85717	0.60086	1.6643	1.1666	1.9416	149
32	0.52992	0.84805	0.62487	1.6003	1.1792	1.8871	148
33	0.54464	0.83867	0.64941	1.5399	1.1924	1.8361	147
34	0.55919	0.82904	0.67451	1.4826	1.2062	1.7883	146
35	0.57358	0.81915	0.70021	1.4281	1.2208	1.7434	145
36	0.58778	0.80902	0.72654	1.3764	1.2361	1.7013	144
37	0.60181	0.79863	0.75355	1.3270	1.2521	1.6616	143
38	0.61566	0.78801	0.78128	1.2799	1.2690	1.6243	142
39	0.62932	0.77715	0.80978	1.2349	1.2867	1.5890	141
40	0.64279	0.76604	0.83910	1.1917	1.3054	1.5557	140
41	0.65606	0.75741	0.86929	1.1504	1.3250	1.5242	139
42	0.66913	0.74314	0.90040	1.1106	1.3456	1.4945	138
43	0.68200	0.73135	0.93251	1.0724	1.3673	1.4663	137
44	0.69466	0.71934	0.96569	1.0355	1.3902	1.4395	136
45	0.70711	0.70711	1.0000	1.0000	1.4142	1.4142	135
46	0.71934	0.69466	1.0355	0.96569	1.4395	1.3902	134
47	0.73135	0.68200	1.0724	0.93251	1.4663	1.3673	133
48	0.74314	0.66913	1.1106	0.90040	1.4945	1.3456	132
49	0.75471	0.65606	1.1504	0.86929	1.5242	1.3250	131
50	0.76604	0.64279	1.1917	0.83910	1.5557	1.3054	130

Natural Trigonometric Functions (*Continued*)

Angle (θ or lag angle), deg.	Sine (or reactive factor)	Cosine (or power factor)	Tangent	Co-tangent	Secant	Cosecant	Angle (θ or lag angle), deg.
51	0.77715	0.62932	1.2349	0.80978	1.5890	1.2867	129
52	0.78801	0.61566	1.2799	0.78128	1.6243	1.2690	128
53	0.79863	0.60181	1.3270	0.75355	1.6616	1.2521	127
54	0.80902	0.58778	1.3764	0.72654	1.7013	1.2361	126
55	0.81915	0.57358	1.4281	0.70021	1.7434	1.2208	125
56	0.82904	0.55919	1.4826	0.67451	1.7883	1.2062	124
57	0.83867	0.54464	1.5399	0.64941	1.8361	1.1922	123
58	0.84805	0.52992	1.6003	0.62487	1.8871	1.1792	122
59	0.85717	0.51504	1.6643	0.60086	1.9416	1.1666	121
60	0.86603	0.50000	1.7320	0.57735	2.0000	1.1547	120
61	0.87462	0.48481	1.8040	0.55431	2.0627	1.1433	119
62	0.88295	0.46947	1.8807	0.53171	2.1300	1.1326	118
63	0.89101	0.45399	1.9626	0.50952	2.2027	1.1223	117
64	0.89879	0.43837	2.0503	0.48773	2.2812	1.1126	116
65	0.90631	0.42262	2.1445	0.46631	2.3662	1.1034	115
66	0.91354	0.40674	2.2460	0.44523	2.4586	1.0946	114
67	0.92050	0.39073	2.3558	0.42447	2.5593	1.0864	113
68	0.92718	0.37461	2.4751	0.40403	2.6695	1.0785	112
69	0.93358	0.35837	2.6051	0.38386	2.7904	1.0711	111
70	0.93969	0.34202	2.7475	0.36397	2.9238	1.0642	110
71	0.94552	0.32557	2.9042	0.34433	3.0715	1.0576	109
72	0.95106	0.30902	3.0777	0.32492	3.2361	1.0515	108
73	0.95630	0.29237	3.2708	0.30573	3.4203	1.0457	107
74	0.96126	0.27564	3.4874	0.28647	3.6279	1.0403	106
75	0.96592	0.25882	3.7320	0.26795	3.8637	1.0353	105
76	0.97029	0.24192	4.0108	0.24933	4.1336	1.0306	104
77	0.97437	0.22495	4.3315	0.23087	4.4454	1.0263	103
78	0.97815	0.20791	4.7046	0.21256	4.8097	1.0223	102
79	0.98163	0.19081	5.1445	0.19438	5.2408	1.0187	101
80	0.98481	0.17365	5.6713	0.17633	5.7588	1.0154	100
81	0.98769	0.15643	6.3137	0.15838	6.3924	1.0125	99
82	0.99027	0.13917	7.1154	0.14054	7.1853	1.0098	98
83	0.99255	0.12187	8.1443	0.12278	8.2055	1.0075	97
84	0.99452	0.10453	9.5144	0.10510	9.5668	1.0055	96
85	0.99619	0.08715	11.430	0.08749	11.474	1.0038	95
86	0.99756	0.06976	14.301	0.06993	14.335	1.0024	94
87	0.99863	0.05234	19.081	0.05241	19.107	1.0014	93
88	0.99939	0.03490	28.634	0.03492	28.654	1.0006	92
89	0.99985	0.01745	57.290	0.01745	57.299	1.0001	91
90	1.00000	0.00000	Infinite	0.00000	Infinite	1.0000	90

2. Fractions of Inch Reduced to Decimal Equivalents

Halves	4ths	8ths	16ths	32ds	64ths	Decimal equivalents	Halves	4ths	8ths	16ths	32ds	64ths	Decimal equivalents
..	..	..	...	....	1/64	0.015625	..	..	..	....	....	33/64	0.515625
..	..	..	....	1/32	....	0.03125	..	..	..	....	17/32	....	0.53125
..	..	..	...	....	3/64	0.046875	..	..	..	....	....	35/64	0.546875
..	..	..	1/16	....	....	0.0625	..	..	..	9/16	....	....	0.5625
..	..	..	...	....	5/64	0.078125	..	..	..	....	....	37/64	0.578125
..	..	..	...	3/32	....	0.09375	..	..	..	....	19/32	....	0.59375
..	..	..	...	....	7/64	0.109375	..	..	..	....	....	39/64	0.609375
..	..	1/8	....	....	....	0.125	..	..	5/8	....	....	....	0.625
..	..	..	...	....	9/64	0.140625	..	..	..	....	....	41/64	0.640625
..	..	..	...	5/32	....	0.15625	..	..	..	....	21/32	....	0.65625
..	..	..	...	....	11/64	0.171875	..	..	..	....	....	43/64	0.671875
..	..	..	3/16	....	....	0.1875	..	..	..	11/16	....	....	0.6875
..	..	..	...	....	13/64	0.203125	..	..	..	....	....	45/64	0.703125
..	..	..	...	7/32	....	0.21875	..	..	..	....	23/32	....	0.71875
..	..	..	...	....	15/64	0.234375	..	..	..	....	....	47/64	0.734375
..	1/4	..	...	....	....	0.25	..	3/4	..	....	....	....	0.75
..	..	..	...	....	17/64	0.265625	..	..	..	....	....	49/64	0.765625
..	..	..	...	9/32	....	0.28125	..	..	..	....	25/32	....	0.78125
..	..	..	...	....	19/64	0.296875	..	..	..	....	....	51/64	0.796875
..	..	..	5/16	....	....	0.3125	..	..	..	13/16	....	....	0.8125
..	..	..	...	....	21/64	0.328125	..	..	..	....	....	53/64	0.828125
..	..	..	...	11/32	....	0.34375	..	..	..	....	27/32	....	0.84375
..	..	..	...	....	23/64	0.359375	..	..	..	....	....	55/64	0.859375
..	..	3/8	....	....	....	0.375	..	..	7/8	....	....	....	0.875
..	..	..	...	....	25/64	0.390625	..	..	..	....	....	57/64	0.890625
..	..	..	...	13/32	....	0.40625	..	..	..	....	29/32	....	0.90625
..	..	..	...	....	27/64	0.421875	..	..	..	....	....	59/64	0.921875
..	..	..	7/16	....	....	0.4375	..	..	..	15/16	....	....	0.9375
..	..	..	...	....	29/64	0.453125	..	..	..	....	....	61/64	0.953125
..	..	..	...	15/32	....	0.46875	..	..	..	....	31/32	....	0.96875
..	..	..	...	....	31/64	0.484375	..	..	..	....	....	63/64	0.984375
1/2	..	..	...	....	....	0.5							

3. In figuring discounts on electrical equipment, it is often necessary to apply primary and secondary discounts. By using the values in Table 4, time and labor may be conserved. To find net price, multiply the list or gross price by the multiplier from the table which corresponds to the discounts.

Example.—The discount on iron conduit may be quoted as 25 and 10 with 2 per cent for cash in 10 days. To obtain the actual cost, 25 per cent would be deducted from the list price, then 10 per cent from that result, and finally 2 per cent from the second result. Assuming that the list price of 3/4-in. conduit is $12 per 100 ft., its actual price with the 25, 10, and 2 per cent discounts would be:

$12 minus 0.25 × $12 = $12 − $3 = $9
$9.00 minus 0.10 × $9.00 = $9.00 − $0.90 = $8.10
$8.10 minus 0.02 × $8.10 = $8.10 − $0.16 = $7.94

Therefore, the net cost of the conduit would be $7.94 per 100 ft. Now by using the multiplier (from Table 4) corresponding to a primary discount of 25 per cent and secondary discounts of 10 and 2 per cent, which is 0.661,

$$\$12.00 \times 0.661 = \$7.94$$

This is the same result as that obtained by using the longer method.

4. Table for Figuring Total Discount Multiplier by Combining Primary and Secondary Discounts

Primary discount, per cent	Secondary discounts						
	2 %	5 %	10 %	15 %	5 and 2 %	10 and 2 %	10 and 5 %
	Multiplier						
0	0.980	0.950	0.900	0.850	0.931	0.882	0.855
5	0.931	0.902	0.855	0.807	0.884	0.838	0.812
10	0.882	0.855	0.810	0.765	0.838	0.794	0.769
11	0.872	0.845	0.801	0.756	0.829	0.785	0.761
12	0.862	0.836	0.792	0.748	0.819	0.776	0.752
13	0.853	0.826	0.783	0.740	0.810	0.767	0.744
14	0.843	0.817	0.774	0.731	0.801	0.758	0.735
15	0.833	0.807	0.765	0.722	0.791	0.750	0.727
16	0.823	0.798	0.756	0.714	0.782	0.741	0.718
17	0.813	0.788	0.747	0.705	0.773	0.732	0.710
18	0.803	0.779	0.738	0.697	0.763	0.723	0.701
19	0.794	0.770	0.729	0.688	0.754	0.714	0.692
20	0.784	0.760	0.720	0.680	0.745	0.705	0.684
25	0.735	0.712	0.675	0.638	0.698	0.661	0.641
30	0.686	0.665	0.630	0.595	0.652	0.617	0.598
35	0.637	0.617	0.585	0.552	0.605	0.573	0.556
40	0.588	0.570	0.540	0.510	0.559	0.529	0.513
45	0.539	0.522	0.495	0.468	0.512	0.485	0.470
50	0.490	0.475	0.450	0.425	0.465	0.441	0.428
55	0.441	0.427	0.405	0.382	0.419	0.397	0.385
60	0.392	0.380	0.360	0.340	0.372	0.353	0.342
65	0.343	0.333	0.315	0.298	0.326	0.309	0.299
70	0.294	0.285	0.270	0.255	0.279	0.265	0.256

5. Multipliers for Computing Selling Prices Which Will Afford a Given Percentage Profit

Percentage profit desired	To obtain selling price, multiply actual cost (invoice cost + freight) by the following value		Percentage profit desired	To obtain selling price, multiply actual cost (invoice cost + freight) by the following value	
	When percentage profit is based on cost	When percentage profit is based on selling price		When percentage profit is based on cost	When percentage profit is based on selling price
5	1.05	1.053	36	1.36	1.563
6	1.06	1.064	37	1.37	1.588
7	1.07	1.075	38	1.38	1.613
8	1.08	1.087	39	1.39	1.640
9	1.09	1.100	40	1.40	1.667
10	1.10	1.111	41	1.41	1.695
11	1.11	1.124	42	1.42	1.725
12	1.12	1.136	43	1.43	1.754
13	1.13	1.149	45	1.45	1.818
14	1.14	1.163	46	1.46	1.852
15	1.15	1.176	47	1.47	1.887
16	1.16	1.190	48	1.48	1.923
17	1.17	1.204	49	1.49	1.961
18	1.18	1.220	50	1.50	2.000
19	1.19	1.235	52	1.52	2.084
20	1.20	1.250	54	1.54	2.174
21	1.21	1.267	56	1.56	2.272
22	1.22	1.283	58	1.58	2.381
23	1.23	1.299	60	1.60	2.500
24	1.24	1.316	62	1.62	2.631
25	1.25	1.334	64	1.64	2.778
26	1.26	1.352	66	1.66	2.941
27	1.27	1.370	68	1.68	3.126
28	1.28	1.390	70	1.70	3.333
29	1.29	1.409	72	1.72	3.572
30	1.30	1.429	74	1.74	3.847
31	1.31	1.450	76	1.76	4.168
32	1.32	1.471	78	1.78	4.545
33	1.33	1.493	80	1.80	5.000
34	1.34	1.516	90	1.90	10.000
35	1.35	1.539	100	2.00	Infinity

6. Table Showing Percentage Net Profit

Percentage markup above cost	Percentage overhead							
	10%	12%	14%	16%	18%	20%	22%	24%
	Percentage net profit based on selling price for a given percentage overhead based on gross sales							
10	−0.90	−2.90	−4.90	−6.90	−8.90	−10.90	−12.90	−14.90
15	3.05	1.05	−0.95	−2.95	−4.95	−6.95	−8.95	−10.95
20	6.67	4.67	2.67	0.67	−1.33	−3.33	−5.33	−7.33
25	10.00	8.00	6.00	4.00	2.00	0.00	−2.00	−4.00
30	13.08	11.08	9.08	7.08	5.08	3.08	1.08	−0.92
33⅓	15.00	13.00	11.00	9.00	7.00	5.00	3.00	1.00
35	15.93	13.93	11.93	9.93	7.93	5.93	3.93	1.93
40	18.57	16.57	14.57	12.57	10.57	8.57	6.57	4.57
45	21.00	19.00	17.00	15.00	13.00	11.00	9.00	7.00
50	23.33	21.33	19.33	17.33	15.33	13.33	11.33	9.33
55	25.50	23.50	21.50	19.50	17.50	15.50	13.50	11.50
60	27.50	25.50	23.50	21.50	19.50	17.50	15.50	13.50
65	29.40	27.40	25.40	23.40	21.40	19.40	17.40	15.40
70	31.18	29.18	27.18	25.18	23.18	21.18	19.18	17.18
75	32.85	30.85	28.85	26.85	24.85	22.85	20.85	18.85
80	34.45	32.45	30.45	28.45	26.45	24.45	22.45	20.45
85	35.95	33.95	31.95	29.95	27.95	25.95	23.95	21.95
90	37.37	35.37	33.37	31.37	29.37	27.37	25.37	23.37
95	38.72	36.72	34.72	32.72	30.72	28.72	26.72	24.72
100	40.00	38.00	36.00	34.00	32.00	30.00	28.00	26.00

NOTE.— Minus (−) values indicate a net loss.

7. Net Profits.—In figuring the net profit of doing business, Table 6 will be found to be very useful. The table may be used in three ways as explained below.

TO DETERMINE THE PERCENTAGE OF NET PROFIT ON SALES THAT ONE IS MAKING.—Locate, at the top of one of the vertical columns, your percentage overhead—your "cost of doing business" in percentage of gross sales. Locate, at the extreme left of one of the horizontal columns, your percentage markup. The value at the intersection of these two columns will be the percentage profit which you are making.

Example.—If your cost of doing business is 18 per cent of your gross sales and you mark your goods at 35 per cent above cost, your net profit is then 7.93 per cent of gross sales, obtained by carrying down from the column headed 18 per cent and across from the 35 per cent markup.

TO DETERMINE WHAT PERCENTAGE OVERHEAD COST OF DOING BUSINESS WOULD YIELD A CERTAIN NET PROFIT FOR A GIVEN MARKUP PERCENTAGE.—Locate in the extreme left-hand column the percentage that the selling price is marked above the cost price. Trace horizontally across from this value until the percentage net profit desired is located. At the top of the column in which the desired net profit is located will be found the percentage overhead cost of doing business that will allow this profit to be made.

Example.—If the markup is 45 per cent and the profit desired is 15 per cent, an overhead cost of doing business of 16 per cent can be allowed, obtained by carrying across from the 45 per cent markup to the 15 per cent profit and finding that this column is headed by 16 per cent overhead.

To Determine What Percentage Should Be Added to the Cost of Goods in Order to Make a Certain Percentage Net Profit on Sales.—Select the vertical column which shows the percentage cost of doing business at its top. Trace down the column until the desired percentage profit is found; from this value trace horizontally to the extreme left-hand column, in which will be found the markup percentage —the percentage be added to the cost to afford the desired profit.

Example.—It is desired to make a 12 per cent net profit when the cost of doing business is 20 per cent of the gross sales. Select the vertical column with 20 per cent at its top. Trace down the column to locate the net profit desired of 12 per cent. This will be part way between 11.00 and 13.33. Carrying across to the left from these values gives a required percentage markup between 45 and 50, or approximately 47 per cent.

For values which do not appear in the table, approximate results can be obtained by estimation from the closest values in the table. If more accurate results are desired for these intermediate values, the following formulas may be used.

$$P = 100 - h - \frac{10{,}000}{100 + m} \tag{1}$$

or

$$m = \frac{100(P + h)}{100 - (P + h)} \tag{2}$$

or

$$h = 100 - P - \frac{10{,}000}{100 + m} \tag{3}$$

where m = percentage markup based on cost of goods; h = percentage overhead based on gross sales; P = percentage net profit based on selling price.

If you sell your goods at the retail list prices set by the manufacturers, you can use the table by converting the trade discount which you receive to an equivalent percentage markup, according to the following table:

Manufacturer's Discount	Equivalent Percentage Markup	Manufacturer's Discount	Equivalent Percentage Markup
10	11	35	54
15	17½	40	66⅔
20	25	45	81¾
25	33⅓	50	100
30	43		

Intermediate values may be calculated from following formula:

$$m = \frac{100Q}{100 - Q} \tag{4}$$

where m = percentage markup based on cost of goods and Q = manufacturer's discount

CONVERSION FACTORS

("Standard Handbook for Electrical Engineers")

These factors were calculated with a double-length slide rule and checked with those given by Carl Hering in his "Conversion Tables."

8. Length

1 mil = 0.0254 mm. = 0.001 in.
1 mm. = 39.37 mils = 0.03937 in.
1 cm. = 0.3937 in. = 0.0328 ft.
1 in. = 25.4 mm. = 0.083 ft. = 0.0278 yd. = 2.54 cm.
1 ft. = 304.8 mm. = 12 in. = 0.333 yd. = 0.305 m.
1 yd. = 91.44 cm. = 36 in. = 3 ft. = 0.914 m.
1 m. = 39.37 in. = 3.28 ft. = 1.094 yd.
1 km. = 3,281 ft. = 1,094 yd. = 0.6213 mile.
1 mile = 5,280 ft. = 1,760 yd. = 1,609 m. = 1.609 km.

9. Surface

1 cir. mil = 0.7854 sq. mil = 0.0005067 sq. mm. = 0.0000007854 sq. in.

1 sq. mil = 1.273 cir. mil = 0.000645 sq. mm. = 0.000001 sq. in.

1 sq. mm. = 1,973 cir. mil = 1,550 sq. mil = 0.00155 sq. in.

1 sq. cm. = 197,300 cir. mil = 0.155 sq. in. = 0.00108 sq. ft.

1 sq. in. = 1,273,240 cir. mil = 6.451 sq. cm. = 0.0069 sq. ft.

1 sq. ft. = 929.03 sq. cm. = 144 sq. in. = 0.1111 sq. yd. = 0.0929 sq. m.

1 sq. yd. = 1.296 sq. in. = 9 sq. ft. = 0.00836 are = 0.000207 acre.

1 sq. m. = 1,550 sq. in. = 10.7 sq. ft. = 1.195 sq. yd. = 0.000247 acre.

1 acre = 43,560 sq. ft. = 4,840 sq. yd. = 4,047 sq. m. = 0.4047 hectare = 0.004047 sq. km. = 0.001562 sq. mile.

1 sq. mile = 27,880,000 sq. ft. = 3,098,000 sq. yd. = 2,590,000 sq. m. = 640 acres = 2.59 sq. km.

10. Volume

1 cir. mil-ft. = 0.0000094248 cu. in.

1 cu. cm. = 0.061 cu. in. = 0.0021 pt. (liq.) = 0.0018 pt. (dry).

1 cu. in. = 16.39 cu. cm. = 0.0346 pt. (liq.) = 0.0298 pt. (dry) = 0.0173 qt. (liq.) = 0.0148 qt. (dry) = 0.0164 l. or cu. dm. = 0.0036 gal. = 0.0005787 cu. ft.

1 pt. (liq.) = 473.18 cu. cm. = 28.87 cu. in.

1 pt. (dry) = 550.6 cu. cm. = 33.60 cu. in.

1 qt. (liq.) = 946.36 cu. cm. = 57.75 cu. in. = 8 gills (liq.) = 2 pt. (liq.) = 0.94636 l. or cu. dm. = 0.25 gal.

1 l. = 1,000 cu. cm. = 61.023 cu. in. = 2.1133 pt. (liq.) = 1.8162 pt. (dry) = 0.908 qt. (dry) = 0.2642 gal. (liq.) = 0.03531 cu. ft.

1 qt. (dry) = 1,101 cu. cm. = 67.20 cu. in. = 2 pt. (dry) = 0.03889 cu. ft.

1 gal. = 3,785 cu. cm. = 231 cu. in. = 32 gills = 8 pt. = 4 qt. (liq.) = 3.785 l. = 0.1337 cu. ft. = 0.004951 cu. yd.

1 cu. ft. = 28,317 cu. cm. = 1,728 cu. in. = 59.84 pt. (liq.) = 51.43 pt. (dry) = 29.92 qt. (liq.) = 28.32 l. = 25.71 qt. (dry) = 7.48 gal. = 0.03704 cu. yd. = 0.02832 cu. m. or stere.

1 cu. yd. = 46,656 cu. in. = 27 cu. ft. = 0.7646 cu. m. or stere.

1 cu. m. = 61,023 cu. in. = 1,000 l. = 35.31 cu. ft. = 1.308 cu. yd.

11. Weight

1 mg. = 0.01543 gr. = 0.001 g.

1 gr. = 64.80 mg. = 0.002286 oz. (av.)

1 g. = 15.43 gr. = 0.03527 oz. (av.) = 0.002205 lb.

1 oz. (av.) = 437.5 gr. = 28.35 g. = 16 drams (av.) = 0.0625 lb.

1 lb. = 7,000 gr. = 453.6 g. = 256 drams = 16 oz. = 0.4536 kg.

1 kg. = 15,432 gr. = 35.27 oz. = 2.205 lb.

1 ton (short) = 2,000 lb. = 907.2 kg. = 0.8928 ton (long).

1 ton (long) = 2,240 lb. = 1.12 tons (short) = 1.016 tons (metric).

12. Energy

Torque units should be distinguished from energy units: Thus, foot-pound and kilogram-meter for energy, and pound-foot and meter-kilogram for torque (see Sec. **99** for further information on torque).

1 ft.-lb. = 13,560,000 ergs = 1.356 joules = 0.3239 g.-cal. = 0.1383 kg.-m. = 0.001285 B.t.u. = 0.0003766 watt-hr. = 0.0000005051 hp.-hr.

1 kg.-m. = 98,060,000 ergs = 9.806 joules = 7.233 ft.-lb. = 2.34 g.-cal. = 0.009296 B.t.u. = 0.002724 watt-hr. = 0.000003704 hp.-hr. (metric).

1 B.t.u. = 1,055 joules = 778.1 ft.-lb. = 252 g.-cal. = 107.6 kg.-m. = 0.5555 lb.-centigrade heat unit = 0.2930 watt-hr. = 0.252 kg.-cal. = 0.0003984 hp.-hr. (metric) = 0.0003930 hp.-hr.

1 watt-hr. = 3,600 joules = 2,655.4 ft.-lb. = 860 g.-cal = 367.1 kg.-m. = 3.413 B.t.u. = 0.001341 hp.-hr.

1 hp.-hr. = 2,684,000 joules = 1,980,000 ft.-lb. = 273,700 kg.-cm. = 745.6 watt-hr.

1 kw.-hr. = 2,655,000 ft.-lb. = 367,100 kg.-m. = 1.36 hp.-hr. (metric) = 1.34 hp.-hr.

13. Power

1 g.-cm. per sec. = 0.00009806 watt.

1 ft.-lb. per min. = 0.02260 watt = 0.00003072 hp. (metric) = 0.00000303 hp.

1 watt = 44.26 ft.-lb. per min. = 6.119 kg.-m. per min. = 0.001341 hp.

1 hp. = 33,000 ft.-lb. per min. = 745.6 watts = 550 ft.-lb. per sec. = 76.04 kg.-m. per sec. = 1.01387 hp. (metric).

1 kw. = 44,256.7 ft.-lb. per min. = 101.979 kg.-m. per sec. = 1.3597 hp. (metric) = 1.341 hp. = 1,000 watts.

14. Resistivity

1 ohm per cir. mil-ft. = 0.7854 ohm per sq. mil-ft. = 0.001662 ohm per sq. mm. m. = 0.0000001657 ohm per cu. cm. = 0.00000006524 ohm per cu. in.

1 ohm per sq. mil-ft. = 1.273 ohms per cir. mil-ft. = 0.002117 ohm per sq. mm. m. = 0.0000002116 ohm per cu. cm. = 0.00000008335 ohm per cu. in.

1 ohm per cu. in. = 15,280,000 ohms per cir. mil-ft. = 12,000,000 ohms per sq. mil-ft. = 25,400 ohms per sq. mm.-m. = 2.54 ohms per cu. cm.

15. Current Density

1 amp. per sq. in. = 0.7854 amp. per cir. mil = 0.155 amp. per sq. cm. = 1,273,000 cir. mils per amp. = 0.000001 amp. per sq. mil.

1 amp. per sq. cm. = 6.45 amp. per sq. in. = 197,000 cir. mils per amp.

1,000 cir. mils per amp. = 1,273 amp. per sq. in.

1,000 sq. mils per amp. = 1,000 amp. per sq. in.

16. Centigrade and Fahrenheit Thermometer Scales

Deg. C.	Deg. F.	Deg. C.	Deg. F.	Deg. C.	Deg. F.	Deg. C.	Deg. F.	Deg. C.	Deg. F.
0	32.	21	69.8	41	105.8	61	141.8	81	177.8
1	33.8	22	71.6	42	107.6	62	143.6	82	179.6
2	35.6	23	73.4	43	109.4	63	145.4	83	181.4
3	37.4	24	75.2	44	111.2	64	147.2	84	183.2
4	39.2	25	77.	45	113.	65	149.	85	185.
5	41.	26	78.8	46	114.8	66	150.8	86	186.8
6	42.8	27	80.6	47	116.6	67	152.6	87	188.6
7	44.6	28	82.4	48	118.4	68	154.4	88	190.4
8	46.4	29	84.2	49	120.2	69	156.2	89	192.2
9	48.2	30	86.	50	122.	70	158.	90	194.
10	50.	31	87.8	51	123.8	71	159.8	91	195.8
11	51.8	32	89.6	52	125.6	72	161.6	92	197.6
12	53.6	33	91.4	53	127.4	73	163.4	93	199.4
13	55.4	34	93.2	54	129.2	74	165.2	94	201.2
14	57.2	35	95.	55	131.	75	167.	95	203.
15	59.	36	96.8	56	132.8	76	168.8	96	204.8
16	60.8	37	98.6	57	134.6	77	170.6	97	206.6
17	62.6	38	100.4	58	136.4	78	172.4	98	208.4
18	64.4	39	102.2	59	138.2	79	174.2	99	210.2
19	66.2	40	104.	60	140.	80	176.	100	212.
20	68.								

For values not appearing in the table use the following formulas:

$$\text{Temp. °C.} = \tfrac{5}{9} \times (\text{Temp. °F.} - 32) \quad (5)$$

$$\text{Temp. °F.} = (\tfrac{9}{5} \times \text{Temp. °C.}) + 32 \quad (6)$$

GRAPHICAL ELECTRICAL SYMBOLS

17. Standard Graphical Electrical Symbols.—In Secs. **18** to **20** are reproduced the standard graphical symbols of the American Institute of Electrical Engineers for one-line and complete diagrams of electrical power apparatus and associated equipment. These symbols are intended for use on maps, connection diagrams, and system wiring diagrams for electrical power apparatus in power houses, substations, and transmission and distribution systems. The standards were approved by the Board of Directors, A.I.E.E., on May 20, 1932, and by the American Standards Association on Sept. 1, 1933. Frequently it is desirable to add abbreviated descriptive notes adjacent to the symbol on the diagram in which it is used. In the tables, under Optional Notes, are given the standardizing committee's suggested lists of notes for various types of equipment.

18. General Symbols for Maps and Connection Diagrams

Name	One line	Complete
Wiring Diagrams[a]		
1. Conductors		
2. Conductors, crossing but not connected		
3. Conductors crossing and electrically connected		
4. Bus (with branches)		
5. Conductors with branches		
6. Ground connection		
Maps[b]		
7. Generating station		
8. Substation		
9. One or more circuits overhead		
10. One or more circuits underground		
11. Overhead line on pole		
12. Overhead line on tower		
13. Street lamp		

Name	Symbol
Winding Connections	
14. Two-phase, three-wire	
15. Two-phase, four-wire	
16. Three-phase delta (or mesh)	
17. Three-phase Y (or star)	
18. Three-phase Y (or star) with neutral brought out and grounded	
19. Three-phase zigzag	
20. Three-phase T	
21. Six-phase, double-delta	
22. Six-phase hexagonal (or chordal)	
23. Six-phase diametrical (or star)	
24. Six-phase diametrical (or star) with neutral brought out and grounded	

[a] The thickness of the line varies according to the importance of the circuits; compare "Conductors" with "Bus," for example.

[b] On maps and connection diagrams, when required, show additional information, such as type of station—steam, hydro, or diesel; description of circuits—number of conductors, size, voltage, and frequency; and type of supporting structure—steel tower, steel pole, strain tower, and height.

19. Symbols for Instruments and Relays

Instruments	One line[a]
1. Indicating instrument (basic symbol)	[b] (I)
2. Graphic instrument (basic symbol)	◯ Graph
3. Ampere-hour meter	(AH)
4. Ammeter	(A)
5. Frequency meter	(F)
6. Generator voltage regulator	(Reg)
7. Ground detector	(GD)
8. Power-factor meter	(PF)
9. Reactive volt-ampere meter	(RVA)
10. Maximum demand meter	(MD)
11. Watthour meter	(WH)
12. Wattmeter	(W)
13. Synchroscope	(S)
14. Voltmeter	(V)
15. Contact-making voltmeter	(CMV)
16. Ammeter switch	[c] A.Sw.
17. Voltmeter switch	V.Sw.
18. Voltmeter receptacle	V.Rec.

Relays	One line[d,e]
19. Relays (basic symbol)	[d] [e] (R)
20. Overcurrent	←→
21. Overvoltage	←V→
22. Overpower	←W→
23. Undercurrent	⟩—≺
24. Undervoltage	⟩—V—≺
25. Underpower	⟩—W—≺
26. Power directional	→
27. Distance or impedance, nondirectional	←Z→
28. Distance or impedance, directional	—Z→
29. Different current	←X→
30. Differential power	—X→
31. Pilot wire	⋈ ⋈
32. Temperature	⊢—◁
33. Phase balance current	←⊞→
34. For ground relay application add ground symbol to relay symbol, thus	←→⏚

Relay Time Designations
(When necessary to establish time functions use the following in addition to function designations)

35. Instantaneous (no time delay)	Inst.
36. Inverse time delay	I.T.
37. Definite time delay	D.T.

[a] For complete symbol show outline approximating that of rear view of actual device and indicate terminals in actual relative location, current terminals by open circles and potential terminals by solid circles. Scale range and type number may be marked adjacent to symbol, if desired.

[b] Letter within circle indicates type of instrument if but one is used. If more than one instrument is used "I" appears within the circle with abbreviation alongside.

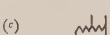
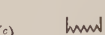
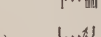
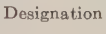
[c] For use adjacent to instrument symbol.

[d] Relay designations appear beside the *R* circle. For system diagrams, current transformer symbols may be omitted and relay designations placed beside the oil-circuit-breaker symbol.

[e] For complete line symbol show outline approximating that of rear view of actual device and indicate terminals in actual relative location, current terminals by open circles and potential terminals by solid circles. Tripping circuit may be identified by representation of contacts within outline.

20. Symbols for Power Apparatus

Name	One line	Complete[a]
1. A-c generator or motor—basic symbol[b]		(c)
2. Induction motor		(c)
3. Induction motor with slip-ring rotor		(c)
4. Synchronous generator or motor with separately excited field		(c)
5. Synchronous converter[d] Optional Notes.—Applies to Symbols 1 to 5. Power Capacity Rating Voltage Rating Number of Phases Frequency Power Factor Speed Per Cent Transient Reactance Horizontal or Vertical Machine Prime Mover or Driven Machine Manufacturer's Designation		(c)
6. D-c generator or motor (basic symbol)[b]		
7. D-c generator or motor with shunt and series field Optional Notes.—Applies to Symbols 6 and 7. Power Capacity Rating Voltage Rating Speed Horizontal or Vertical Machine Prime Mover or Driven Machine Manufacturer's Designation		(c)
8. Direct-connected units (basic symbol)[e]		(c)
9. Single-phase two-winding transformer (basic symbol)[f]		(c)

Name	One line	Complete[a]
10. Polyphase two-winding transformer (basic symbol)[f,g]		(c)
11. Three-winding transformer[f,g]		(c)
12. Autotransformer[f,g]		(c) 
13. Transformer with taps[f,g]		(c) 
14. Constant-current transformer[g,h] Optional Notes.—Applies to Symbols 9 to 14. Power Capacity Rating Number of Phases Voltage Rating of Each Winding Method of Cooling Tap Voltages Secondary Amperes (for Constant-current Trans.) Per Cent Reactance Frequency Manufacturer's Designation		(c) 
15. Current transformer[f] Optional Notes.—Applies to Symbol 15. Number of Units (if one line) Power Capacity Rating Current Rating Manufacturer's Designation		
16. Potential transformer[f] Optional Notes.—Applies to Symbol 16. Number of Units (if one line) Power Capacity Rating Voltage Rating Manufacturer's Designation		

17. Induction voltage regulator.....
OPTIONAL NOTES.—Applies to Symbol 17.
Number of Units (if one line) — Per Cent Buck or Boost
Power Capacity Rating — Hand or Automatic Operated
Voltage Rating — Number of Phases
Current Rating — Y or Delta Connected
Method of Cooling — Manufacturer's Designation
Frequency

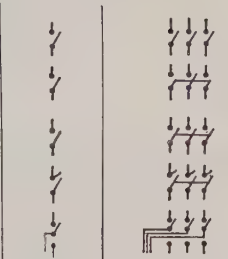
18. Disconnecting switch (basic symbol).....

19. Knife switch, single throw.....

20. Disconnecting switch, group operated.....

21. Air-break switch, horn gap, group operated.....

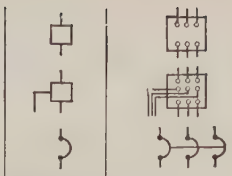
22. Double-throw switch.....
OPTIONAL NOTES.—Applies to Symbols 18 to 22
Number of Units (if one line) — Method of Operation (if other than hand operated)
Voltage Rating — Manufacturer's Designation
Current Rating
Number of Poles



23. Oil circuit breaker, single throw...

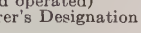
24. Oil circuit breaker, double-throw..

25. Air circuit breaker.....
OPTIONAL NOTES.—Applies to Symbols 23 to 25
Voltage Rating — Current Rating
Number of Poles — Method of Operation
Interrupting Capacity at Operating Voltage — Automatic Reclosing
Manufacturer's Designation



26. Fuse.....
OPTIONAL NOTES.—Applies to Symbol 26.
Voltage Rating — Open, Closed, Plug, Expulsion or Liquid Filled
Current Rating
Interrupting Capacity — Manufacturer's Designation

27. Resistor.....

This symbol has not been approved as American Standard because in radio symbols (A.I.E.E. 17g3-A.S.A. Z10g4) the symbol is  At present these are irreconcilable.

It is recognized that no symbol list can show symbols for complete diagrams for all possible methods of connection.

[a] The "complete" symbol is intended to illustrate the method of treatment for any desired polyphase combination rather than to show the exact symbol required.

[b] For motor use *M* within symbol if necessary to distinguish.

[c] Use symbol ( ) for windings of apparatus as required and connect to suit particular case.

[d] See also item 6.

[e] Use particular symbols and join as here shown.

[f] This symbol has not been approved as American Standard because in radio symbols (A.I.E.E. 17g3-A.S.A. Z10g3) it is preferred to use looped lines to indicate the winding and in the case of iron-core transformers to use parallel lines between the windings to indicate the iron core. At present these are irreconcilable.

[g] Inscribe winding connection diagram symbol from Sec. **18** (14 to 24).

[h] This symbol has not been approved as American Standard because in radio symbols (A.I.E.E. 17g3-A.S.A. Z10g3) it is preferred to use looped lines to indicate the winding and in the case of iron-core transformers to use parallel lines between the windings to indicate the iron core. This symbol is used to indicate an air-core transformer with variable coupling in radio symbols (A.I.E.E. 17g3-A.S.A. Z10g3). At present these are irreconcilable.

Symbols for Power Apparatus (*Continued*)

Name	One line	Complete[a]
28. Rheostat		
OPTIONAL NOTES.—Applies to Symbols 27 and 28.		
Voltage Rating	Ohmic Rating	
Current Rating	Manufacturer's Designation	
29. Reactor		
OPTIONAL NOTES.—Applies to Symbol 29.		
Number of Units (if one line)	Per cent Reactance	
Power Capacity Rating	Number of Phases	
Voltage Rating	Frequency	
Current Rating	Manufacturer's Designation	
Reactive Voltage Rating		
30. Capacitor		
This symbol has not been approved as American Standard because in radio symbols (A.I.E.E. 17g3-A.S.A. Z10g3) the symbol is . At present these are irreconcilable.		
OPTIONAL NOTES.—Applies to Symbol 30.		
Number of Units (if one Line)	Capacitance Rating	
Power Capacity Rating	Frequency	
Voltage Rating	Number of Phases	
Current Rating	Manufacturer's Designation	
31. Lightning arrester (basic symbol)		

Name	One line	Complete[a]
This symbol has not been approved as American Standard because in railway symbols (A.I.E.E. 17g5 A.S.A. Z10g5) the symbol is . At present these are irreconcilable.		
OPTIONAL NOTES.—Applies to Symbol 31.		
Number of Units (if one Line)		
Voltage Rating		
Type: (Electrolytic, Aluminum cell, Valve, Film, Multigap, Horn Gap, etc.) Manufacturer's Designation		
32. Pothead cable terminal		
33. Mercury-arc rectifier		
OPTIONAL NOTES.—Applies to Symbol 33.		
Power Capacity Rating	Frequency	
Voltage Rating A.-c. and D.-c.	Manufacturer's Designation	
Current Rating A.-c. and D.-c.		
34. Battery[i]		
OPTIONAL NOTES.—Applies to Symbol 34.		
Power Capacity Rating	Number of Cells	
Voltage Rating	Manufacturer's Designation	
35. Instrument shunt		
36. Lamp		

[a] The "complete" symbol is intended to illustrate the method of treatment for any desired polyphase combination rather than to show the exact symbol required.

[i] Polarity should be indicated.

PRINCIPLES OF ELECTRICITY AND MAGNETISM—UNITS

21. Magnets and Magnetism.—Any body which has the ability to attract iron or steel is called a magnet. The attractive ability of such a body is called magnetism. Certain specimens of iron ore sometimes possess the property when they are taken from the earth. Such natural specimens will attract and hold iron filings and are called natural magnets or loadstones. The attraction for the filings will be greatest at two ends as illustrated in Fig. 1. The two ends that have the greatest attraction for the iron filings are called the **poles** of the magnet. If a natural magnet were suspended by a string from its center so that it were free to turn, it would be found that the magnet would turn until the axis through its poles is lying north and south. The end or pole which is pointing north is called the **north pole** of the magnet, and the other end or pole, which is pointing south, is called the **south pole.**

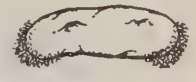


FIG. 1.—Loadstone with iron filings.

It is possible by certain means discussed in Sec. **24** to produce artificial magnets, *i.e.*, to magnetize a piece of iron or steel that did not originally in its natural state possess the property of magnetism. Artificial magnets are of two types (1) temporary and (2) permanent. **Temporary magnets** are those which will hold their magnetism only as long as the magnetizing force is maintained. **Permanent magnets** are those which will hold their magnetism after the magnetizing force has been removed and continue to be magnets for a long period of time unless they are demagnetized by some means such as by being jarred or heated.

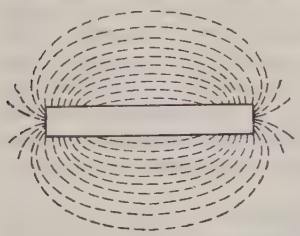


FIG. 2.—Arrangement of iron filings around a magnet.

Any material that can be magnetized or that is attracted by a magnet is called a magnetic material.

22. Magnetic Field.—The region around a magnet has peculiar properties that exist only as long as the magnet is present. This property of the region around a magnet is that there will be a force exerted upon any piece of magnetic material if it is placed in the space in proximity to the magnet. This property or condition of the space around a magnet is called a magnetic field. If a magnet is covered with a sheet of paper sprinkled with iron filings, the filings will arrange themselves in definite curves extending from pole to pole, as shown in Fig. 2. The direction taken by the filings shows the direction of the magnetic field, *i.e.*, the direction of the force exerted upon a magnetic material if placed in the region around the magnet. The presence of this property (magnetic field) in the space around a magnet can also be demonstrated by means

of a compass needle. A compass needle is a small, light magnet suspended so that it can turn freely. If a compass needle is placed in the region around a magnet, it will turn into a definite position, thereby demonstrating that there is a force acting upon a magnetic material placed in the region around a magnet. The magnitude or strength of the magnetic field, *i.e.*, the magnitude of the force exerted upon a magnetic material in the space around a magnet, will be different at different points. The field will be strongest at the poles.

The direction of a magnetic field at any point is the direction in which a force is exerted upon the north pole of a compass needle if placed at that point in the field. It will be the direction in which the north pole end of the axis of the compass needle points.

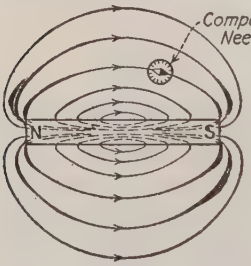


FIG. 3.—Lines of magnetic flux around a bar magnet.

23. Magnetic Flux.—The magnetic field of a magnet may be depicted by curved lines from the north to the south pole as shown in Fig. 3. Arrows placed on the lines, which are picturing the condition in the space, indicate the direction of the force that would be exerted upon the north pole of a compass needle at that point. The density with which the lines are drawn represent the magnitude of the field, *i.e.*, the magnitude of the force that would be exerted upon a magnetic material placed at that point in the field. These lines, which picture the condition in the space around a magnet, are called lines of magnetic flux or simply magnetic flux.

24. Methods of Producing Artificial Magnets.—A magnetic material can be magnetized to a certain degree by stroking it with a permanent magnet or by placing it in the field of another magnet. Either of these means will normally produce only relatively weak magnets. The general method of magnetizing a material or of producing a magnetic field is by means of passing an electric current through a coil of wire (see Secs. **57** and **58**).

25. The electron theory states that all matter is made of electricity.—Matter is anything which has weight and occupies space; see the author's "Practical Electricity." All matter is made up of molecules, of which there are millions of different kinds. Molecules are made up of atoms, of which there are but 96 different kinds. That is, there are but 96 elements now known. All atoms are believed to be composed of electrons, which are minute particles of negative electricity which are, normally, held in place in each atom by a positively charged, electrical something which has been named the nucleus.

NOTE.—The electrons thus interlocked in the atoms are, it is believed, constantly revolving at great speeds in regular circular orbits around the positive nuclei. In this,

they may be thought of as resembling the eight satellites which rotate about the planet Saturn. In a normal atom the amount of negative electricity of the electrons is exactly neutralized by an equal amount of opposite or positive electricity of the nucleus. Thus a normal atom exhibits no external sign of electrification.

26. The different kinds of atoms (the atoms of the different elements) differ only in the number of and the arrangement of the electrons and in the magnitude of the positive nuclei which compose them. The lighter elements have few electrons; the heavier elements many. A normal atom of any given element always has the same number of electrons and a positive nucleus of the same magnitude.

Examples.—An atom of hydrogen, the lightest element, it is believed, consists of one electron and a corresponding positive nucleus. An atom of uranium, the heaviest element, has probably 92 electrons and a correspondingly greater positive nucleus.

27. Thus everything about us, all matter, is composed of electricity.—The electrons can, under certain circumstances, be forced from the atoms. The positive nuclei, except under very special conditions (disruption of the atom), cannot be moved from the atom. Electrical phenomena occur when some of this electricity (electrons) is moved or when the electrical balance which normally obtains within the atoms is disturbed.

28. Electrons are exceedingly small.—It is estimated that each has a diameter of about a thirteen million millionth of an inch $\left(\frac{1}{12{,}700{,}000{,}000{,}000}\text{ in.}\right)$. An electron weighs about one thirty billion billion billionth of an ounce

$$\left(\frac{1}{31{,}500{,}000{,}000{,}000{,}000{,}000{,}000{,}000}\text{ oz.}\right)$$

or about an eighteen hundredth ($\frac{1}{1845}$) as much as does an atom of hydrogen.

29. Electricity cannot be generated.—It is evident that there is in the universe a certain definite amount of electricity. Electricity can neither be created nor destroyed. It can, however, be forced to move and thus transmit power or produce electrical phenomena. Electrical energy (not electricity) can be generated (*i.e.*, produced, from energy of some other form) by forcing electrons to move in certain paths.

30. An e.m.f. is the name which has been given to that tendency —measured in **volts**—which makes electrons move or tends to do so. Thus, if an e.m.f. is impressed across the two ends of a wire, it will force the electrons of the atoms which compose the wire to move from atom to atom, in the direction of the e.m.f., along through the wire, assuming, of course, that a closed conducting path is provided. A lightning flash is merely a movement of electrons between the atoms of the atmosphere caused by an e.m.f. or voltage existing between the clouds and the earth.

31. An electric current—measured in **amperes**—consists of a movement or flow of electricity. Thus the thing which we call an electric current is merely a shifting of electricity, usually motion of electrons from atom to atom. If an electric current exists in a wire, there is then a flow of electrons in that wire. Whenever there is a movement of electrons there is an electric current.

32. Electric currents may be divided into two general classes (1) direct currents, (2) alternating currents.

33. A direct current is one which flows always in the same direction.

34. An alternating current is one the direction of which is reversed at regular intervals.

35. Further classifications of direct currents are (1) continuous currents, which are steady, nonpulsating, direct currents; (2) constant currents, which continue to flow for a considerable time in the same direction and with unvarying intensity; (3) pulsating currents, which are regularly varying continuous currents.

36. The coulomb is the name which has been given to the unit of quantity of electricity. It is somewhat analogous to our unit of quantity of water—the gallon. A coulomb of electricity, so calculations show, comprises approximately six million million million electrons. However, it is **rate of flow,** which is measured in amperes, that is of importance to the electrician rather than the total quantity of electricity which flows. Hence, the unit coulomb is almost never directly used in practical work.

37. The ampere is the name which has been given to the practical unit of rate of flow of electricity, and it is analogous to "gallons per minute" in hydraulics. The ampere represents a rate of flow of 1 coulomb per second. That is, it is equivalent to a flow of six million million million electrons per second. It has been internationally agreed (recommended by the Chicago International Electrical Congress of 1893 and legalized by act of Congress 1894) that the ampere shall be defined as "that unvarying current, which, when passed through a solution of nitrate of silver in water in accordance with standard specifications, deposits silver at the rate of one thousand one hundred and eighteen millionths (0.001118) of a gram per second."

NOTE.—The flow of water in a pipe is measured by the quantity of water which flows through it in a second, as 1 gal. per sec., 8 gal. per sec., etc. Similarly, the flow of electricity in a circuit is measured by the amount of electricity that flows through it in a second, as: 1 coulomb per second.

Examples.—If 2 coulombs flow in a second, then the average rate of flow is 2 coulombs per second and the average current is 2 amp. If 20 coulombs flow per second, then the current is 20 amp., etc.

Examples.—The current flowing in an ordinary 40-watt incandescent Mazda lamp is about $\frac{1}{3}$ amp. Series street-lighting lamps require from 6.6 to 20 amp. The current in a telegraph wire is approximately 0.04 amp.

38. Resistance is the name which has been given to that opposition which is offered by the different materials of the earth to the movement

of the electrons—*i.e.*, to the flow of an electric current—in them. Resistance and its computation are further discussed in succeeding Secs. **40, 68, 70, 71,** and **76** to **84.** The electrons of some materials, the metals for example, can be moved from atom to atom within the material with relative ease, *i.e.*, by the application of a small e.m.f.

39. The materials in which the electrons can be easily moved by an e.m.f. from atom to atom are called conductors.—On the other hand, it is difficult to move, with an e.m.f., the electrons from the atoms of certain other materials, such as air, glass, mica, and porcelain. Such materials are called **insulators.** However, there is no perfect conductor. All materials offer some opposition to the establishment of a current and there is no material in which a current cannot be established, provided the impelling e.m.f. is sufficiently great. Witness again the lightning flash.

40. The ohm is the name which has been given to the practical unit of electrical resistance. It affords a measure whereby the degree of opposition of the different materials to the passage of an electric current through them may be measured. It has been agreed that the International Ohm shall be "represented by the resistance offered, to an unvarying electric current, by a column of mercury, at the temperature of melting ice, 106.3 cm. long and having a cross-sectional area of 1 sq. mm."

Examples.—A piece of No. 14 Brown and Sharpe gage copper wire, a size sometimes used for branch wiring in lighting circuits, 380 ft. long has a resistance of 1 ohm. A piece of No. 10 Brown and Sharpe gage copper wire 1,000 ft. long has a resistance of almost precisely 1 ohm.

41. Conductance is the reciprocal of resistance. The practical unit is called the mho. A circuit having a resistance of 10 ohms will have a conductance of $\frac{1}{10}$ or 0.1 mho.

42. Conductivity.—The relative ease with which an electric current may be passed through a material is called its percentage conductivity. The conductivity of pure annealed copper is taken as the base of reference, so that pure annealed copper is said to have 100 per cent conductivity. Copper of 100 per cent conductivity has a resistance of 10.371 ohms per cir. mil-ft. at 20°C. The resistance per circular mil-foot of any material can be found, if its percentage conductivity is known, by dividing 10.371 by the percentage conductivity of the material.

43. The volt is the unit of e.m.f., *i.e.*, it is the unit whereby the tendency to establish electric currents may be measured. The ampere and the ohm having been arbitrarily defined as above, the volt may now be readily defined:

By international agreement it has been decided that 1 volt shall be taken as that e.m.f. which will establish a current of 1 amp. through a resistance of 1 ohm.

Note.—(V. Karapetoff, "The Electric Circuit.") Whatever the reasons which led originally to the choice of the magnitudes of the ampere and the ohm, these two units

can now be considered as two arbitrary fundamental units established by international agreement. They may be considered as arbitrary units in the same way as the foot and the pound are arbitrary units. Their values can be reproduced to a fraction of 1 per cent, according to detailed specifications adopted by practically all civilized nations. Since their values have been established by international agreement they are called International Electrical Units. These two units (the ampere and the ohm) together with the foot (or inch), the second, and the degree centigrade permit the determination of the values of all other electric and magnetic quantities. Hence, the present system of practical electrical units is properly called the ampere-ohm system.

44. E.M.Fs. may be produced in the following ways:

1. Electromagnetic induction.
2. Heating of contact of unlike substances.
3. Chemical action.
4. Electric fields.
5. Friction.
6. Vibration or heating of crystals.

45. E.M.Fs. may be produced by electromagnetic induction in the following three ways:

1. By moving a conductor across a magnetic field. If the conductor of Fig. 6 is moved up or down so as to cut the lines of flux of the magnetic field between the poles of the magnet, an e.m.f. will be generated between the two ends of the conductor. This is the method employed for the production of voltage in d-c generators (see Sec. **48**).

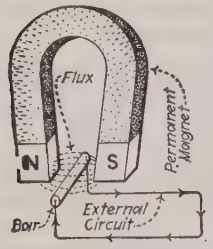


FIG. 4.—E.m.f. generated by magnetic flux.

2. By moving a magnetic field across a conductor. If in Fig. 4 the conductor is held stationary and the magnet is moved up or down so that the lines of flux of the magnetic field between the poles of the magnet will cut the conductor, an e.m.f. will be generated between the two ends of the conductor. This is the method employed for the production of voltage in most a-c generators (see Sec. **137**).

3. By changing the strength of the magnetic field linked with a conductor. If in Fig. 5 an alternating electric current is passed through winding *A*, this current will set up a magnetic field through the iron ring. This magnetic field will be continually changing in strength, owing to the changing magnitude of the current. There will therefore be a continual change in the magnetic flux linked with winding *B*. This change in the magnetic flux linked with *B* will generate a voltage between the two ends of winding *B*. It is this phenomenon that makes possible the operation of transformers (see the division on Transformers).

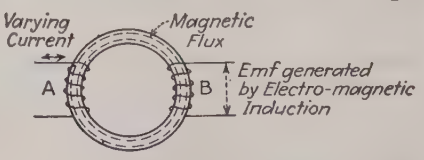


FIG. 5.—Method of producing an e.m.f. by electromagnetic induction.

Wherever large quantities of electrical energy are required, the necessary e.m.f. is produced by one of the means of electromagnetic induction.

46. A Hand Rule to Determine the Direction of an Induced E.M.F. (see Fig. 6).—Use the **right hand.** Extend the thumb in the direction of the motion, or of the equivalent motion, of the conductor and extend the forefinger in the direction of the magnetic flux. Then the middle finger will point in the direction of the induced e.m.f. (Magnetic flux flows from the north (N) to the south (S) pole outside of a magnet; from south to north inside the magnet.) This rule can be remembered by associating the sounds of the following word groups: thumb—motion, forefinger—force, and middle finger—motive force.

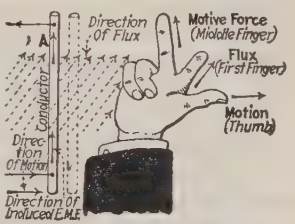


FIG. 6.—Application of right-hand rule.

47. Elementary A-c Generator.—A very simple elementary a-c generator is shown in Fig. 7. As the conductors are revolved through the magnetic field, a voltage will be produced in each conductor. Considering the series circuit formed by the two conductors, the voltages produced by the two conductors will act to send current through the circuit in the same direction. The total voltage between the terminals of the machine will be the summation of the voltages produced by the two conductors at that instant. As long as conductor A is under the north pole and conductor B is under the south pole there will be a terminal voltage which will send current through the external circuit from C to D. When the conductors are midway between poles they will not be cutting any flux, and no voltage will be produced. As conductor A moves under the south pole and conductor B under the north pole, the conductors will again be cutting flux, and there will again be voltages produced in the conductors. The direction of these voltages will, however, be just opposite to the direction of the voltages when A was under the north pole and B under the south pole. The terminal voltage of the machine is therefore periodically reversing in direction, and the machine is an a-c generator.

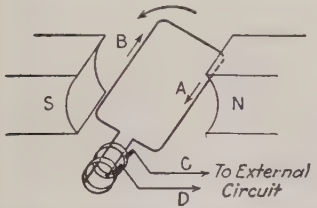


FIG. 7.—Elementary a-c generator.

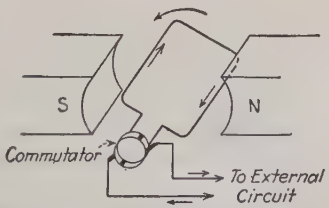


FIG. 8.—Elementary d-c generator.

48. An elementary d-c generator is shown in Fig. 8. The production of voltage in the conductors is exactly the same as for the elementary a-c generator of Sec. **47.** As the conductors revolve, an alternating voltage is produced in them. In order that the terminal voltage may always act upon the external load in the same direction, some device must be inserted between the conductors and the terminals. This device must reverse the connections of the conductors to the external circuit at the instant when the voltage of the conductors is zero and changing in direction. Such a device is called a commutator.

49. The magnitude of the voltage produced by electromagnetic induction depends upon the rate at which the lines of flux are cut by the conductor. Whenever 100,000,000 lines of flux are cut per second, 1 volt is produced. The voltage produced is therefore equal to the number of lines of flux cut per second divided by 100,000,000.

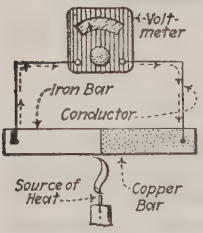


FIG. 9.—E.m.f. generated by heat.

50. Thermocouples.—If heat is applied to the junction of two dissimilar metals (Fig. 9), an e.m.f. will be generated. The magnitude of the e.m.f. produced will depend upon the material of the metals and the difference in temperature between the hot junction and the cold ends. Only very small voltages can be produced in this way, so that the method is not applicable where electrical energy of any quantity is required. However, this method is of great practical value for application in temperature measurements.

51. E.M.Fs. Produced by Chemical Action.—Certain combinations of chemicals will generate e.m.fs. For instance, if a piece of zinc (Fig. 10) and a piece of carbon are immersed in a solution of sal ammoniac, there will be an e.m.f. produced between the zinc and the carbon. Such a combination is called a battery. If the key in Fig. 10 is closed, an electric current will flow and the bell will ring. The voltage of dry cells and storage batteries is produced in this way by chemical action.

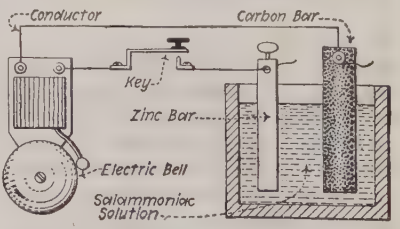


FIG. 10.—E.m.f. generated by chemical action.

52. E.M.Fs. Produced by Electric Fields.—Whenever there is a voltage between two conductors, there are certain conditions produced in the space around and between the conductors. This condition in the surrounding space is called an electric field. A discussion and explanation of this phenomenon are outside the scope of this book. However,

e.m.fs. produced by changes in this electric field are of great practical importance, since these changes induce changing voltages in neighboring conductors. Voltages are produced by this means in telephone lines from neighboring electric power lines and may cause serious interference with communication over the telephone lines.

53. E.M.Fs. Produced by Friction.—E.m.fs. of considerable magnitude may be produced by the rapid rubbing together of different materials. Practical illustrations of voltages produced by this means are voltages on belts, produced by slipping of the belt on the pulley, and voltages between automobile bodies and ground, produced by the revolution of the rubber tires over the road.

54. E.M.Fs. Produced by Crystals.—Certain crystals, such as quartz and rochelle salt crystals, have the property of producing very small e.m.fs. between opposite faces of the crystals when the crystals are subjected to a pressure. Certain crystals, such as tourmaline, when heated produce a very small e.m.f. between opposite faces. Although e.m.fs. produced by these means are of very small magnitude, still they are of great practical value in microphones and instruments for the measurement of vibrations in machinery.

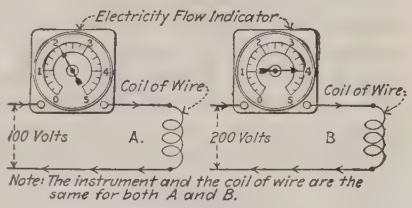


FIG. 11.—Illustrating the effect of increasing voltage.

55. E.M.F., which is measured in volts, causes electricity to flow. A higher voltage is required to force a given current of electricity through a small wire than through a large one. If the voltage impressed on a circuit is increased the current will be correspondingly increased (see Fig. 11).

56. The distinction between amperes and volts should be clearly understood. The amperes represent the rate of electricity flow (see Secs. **31** and **37**) through a circuit while the volts represent the tendency causing the flow. There may be a tendency (voltage) and yet no current. If the path of electricity is blocked by an open switch (Fig. 12), there will be no current of electricity, though the tendency to produce (voltage) may

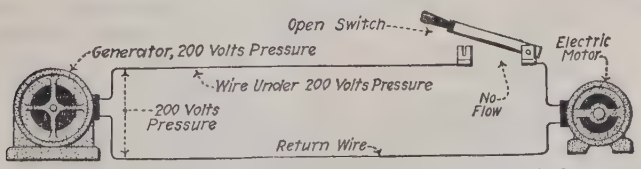


FIG. 12.—Electricity flow blocked by an open switch.

be high. With a given voltage a greater current of electricity will flow through a large wire than through a small one.

57. Effects of an Electric Current.—The two principal effects of an electric current are (1) heating effect and (2) magnetic effect.

Whenever an electric current passes through a material, there is a heating effect due to the current. This effect is indicated by the increase in temperature of the material. A certain portion of the electrical energy that is put into the circuit is transformed into heat energy owing to the opposition offered to the flow of current by the resistance of the material. This loss of electrical energy (transferred to heat energy) is associated with a drop in voltage. This drop in voltage is produced by the amount of voltage that is required to force the current through the resistance. This heating effect with its associated drop of voltage and temperature rise of the material always takes place any time a current is passed through a circuit.

There is an association between electricity and magnetism because a magnetic field can be produced by an electric current. In fact, whenever an electric current is passed through a conductor, the electric current tends to set up a magnetic field around the conductor. The presence of this field can be demonstrated by holding a compass near a wire that is carrying a current (Fig. 18). The compass needle will be deflected in a definite direction depending upon the direction of flow of the current.

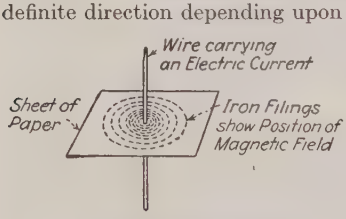


FIG. 13.—Magnetic field around a conductor.

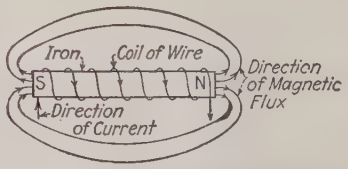


FIG. 14.—Elementary electromagnet.

58. Magnetic Effect of Electric Current.—The magnetic lines of flux (magnetic field) that are produced by a current passing through a straight wire can be determined by passing the wire through a sheet of paper upon which iron filings are sprinkled as illustrated in Fig. 13. The direction of the lines of flux will be in concentric circles around the axis of the conductor. The field will be strongest close to the conductor.

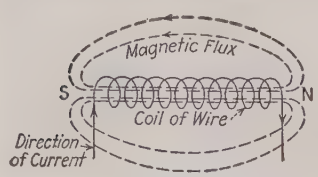


FIG. 15.—Magnetic field from current flowing through a coil of wire.

If current is passed through a coil of wire wound around a piece of iron, as in Fig. 14, it will be found that the iron is magnetized in a definite direction. Such a magnet is called an electromagnet. This is the method

always employed for producing strong magnets or setting up strong magnetic fields. A coil of wire carrying current will act like a magnet and will produce a magnetic north pole at one end and a magnetic south pole at the other (see Fig. 15). The direction of the magnetic field produced will be from the north pole end around through the space outside of the coil to the south pole end and thence back through the interior of the coil to the north pole end.

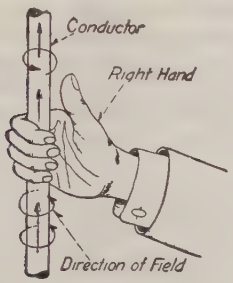


FIG. 16.—Hand rule for direction of field.

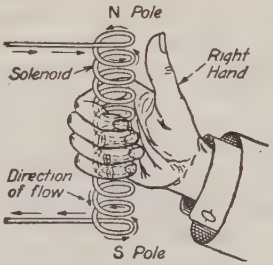


FIG. 17.—Hand rule for determining polarity of a solenoid.

59. Hand Rule for Direction of Magnetic Field about a Straight Wire (see Fig. 16).—If a wire through which electricity is flowing is so grasped with the **right hand** that the thumb points in the direction of electricity flow, the fingers will point in the direction of the magnetic field and vice versa.

60. Hand Rule for Polarity of a Solenoid or Electromagnet (see Fig. 17). If a solenoid or an electromagnet is so grasped with the **right hand** that the fingers point in the direction of electricity flow, the thumb will point toward the north pole.

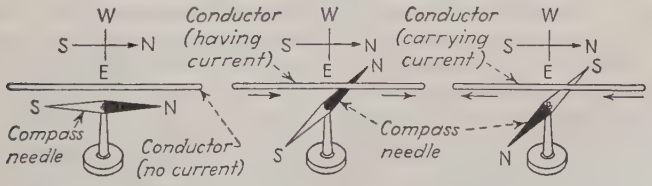


FIG. 18.—Performance of a compass needle near a conductor.

61. Rule for Determining Direction of Current Flow with a Compass (see Fig. 18).—If a compass is placed under a conductor in which electricity is flowing from south to north, the north end of the needle will be deflected to the west. If the compass is placed over the conductor, the north end of the compass will be deflected to the east. If the direction of current flow in the conductor is reversed, the direction of deflection of the needle will be reversed correspondingly.

62. Symbols for indicating the direction of an e.m.f. or currents into or out of the end of a conductor are shown in Fig. 19.

63. Ohm's Law.—From the preceding sections it is evident that a voltage is required to force a current through a circuit against the resistance caused by the material of the conductor. The relation between current, resistance, and voltage is known as Ohm's law. It is merely a restatement, as applied to electric circuits, of the general law which governs all physical phenomena, *i.e.*, the result produced is directly proportional to the effort or cause and inversely proportional to the opposition. In an electric circuit the current established is the result. The e.m.f. which establishes it is the effort; the opposition is represented by the resistance. Thus it may be written for an electric circuit:

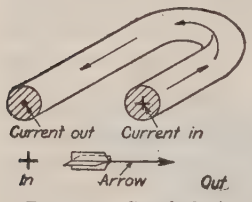


FIG. 19.—Symbols indicating direction of current flow.

$$I = \frac{E}{R} = \left(\text{amperes} = \frac{\text{volts}}{\text{ohms}}\right) \qquad \text{(amperes)} \quad (7)$$

$$R = \frac{E}{I} = \left(\text{ohms} = \frac{\text{volts}}{\text{amperes}}\right) \qquad \text{(ohms)} \quad (8)$$

$$E = I \times R = (\text{volts} = \text{amperes} \times \text{ohms}) \qquad \text{(volts)} \quad (9)$$

where I = the current, in amperes, which flows in the circuit or in the portion of the circuit under consideration; R = the resistance in ohms of the circuit or the portion of the circuit under consideration; and E = the e.m.f. in volts required to force the current through the resistance of the circuit or the portion of the circuit under consideration.

64. Application of Ohm's Law.—Great care must be exercised in the use of Ohm's law. The voltage given by Eq. (9) may or may not be the voltage that must be impressed on the circuit in order to force the given current through the circuit. When the circuit contains only resistance, then the voltage given by Ohm's law is the voltage impressed on the circuit. Ohm's law holds true for all circuits both direct and alternating, but the voltage obtained by its use is only the voltage required to overcome the resistance of the circuit. Ohm's law cannot be used for a complete motor circuit in order to determine the resistance of the circuit.

65. Use Ohm's law for:

1. Complete d-c circuits which do not contain any e.m.f. other than the impressed voltage.
2. Conductors or resistors of d-c circuits.
3. Any circuit which consists only of resistance.
4. Any portion of a circuit containing only resistance.

66. Do not use Ohm's law for:

1. A-c circuits in general.
2. Complete motor circuits.

3. Complete circuits containing any e.m.f. other than the impressed voltage.

Refer to Secs. **125** and **126** for calculation of a-c circuits.

67. Ohm's law may be applied to an entire circuit or to a portion of a circuit.—Errors are frequently made, in applying Ohm's law, by considering the voltage of one part of a circuit, the current of another part, and the resistance of still another part; the result is inconsistent. When applied to an entire circuit, the amperes in the entire circuit equal the volts across the entire circuit divided by the resistance of the entire circuit. When applied to a portion of the circuit, the current in that portion of the circuit equals the voltage across the portion divided by the resistance of that portion.

68. Examples of the application of Ohm's law.

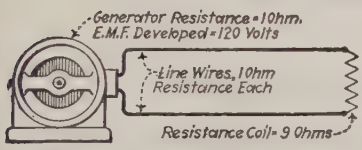


FIG. 20.—An entire dynamo circuit.

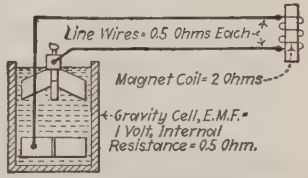


FIG. 21.—An entire battery circuit.

Example.—What will be the current in the d-c circuit of Fig. 20?

Solution.—An entire circuit is shown. It is composed of a dynamo, line wires, and a resistance coil. The e.m.f. developed by the dynamo (do not confuse this with the e.m.f. impressed by the dynamo on the line) is 120 volts. The resistance of the entire circuit is the sum of the resistances of dynamo, line wires, and resistance coil. Substituting in the formula:

$$I = \frac{E}{R} = \frac{120}{1 + 1 + 9 + 1} = \frac{120}{12} = 10 \text{ amp.}$$

Example.—What current will flow in the circuit of Fig. 21?

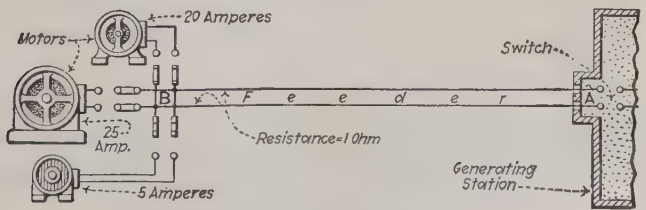


FIG. 22.—Feeder to motors.

Solution.—This again is an entire circuit. Substituting in the formula:

$$I = \frac{E}{R} = \frac{1}{0.5 + 0.5 + 2 + 0.5} = \frac{1}{3.5} = 0.28 \text{ amp.}$$

Note that the internal resistance of the battery must be considered.

Example.—With 10 amp. flowing, what will be the voltage drop in the line wires in Fig. 22?

Solution.—Each has a resistance of 1.0 ohm, hence

$$E = I \times R = 10 \times 2 = 20 \text{ volts}$$

Example.—What is the resistance of the incandescent lamp of Fig. 23, *A*? It is tapped to a 120-volt circuit, and the ammeter reads 0.5 amp. The branch wires are so short that their resistance can be neglected.

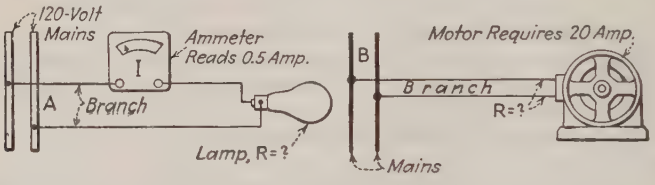


FIG. 23.—Portions of circuit.

Solution.—Substitute in the formula,

$$R = \frac{E}{I} = \frac{120}{0.5} = 240 \text{ ohms}$$

Example.—The motor of Fig. 23, *B* takes 20 amp., and the drop in voltage in the branch wires should not exceed 5 volts. What is the greatest resistance that can be permitted in the branch conductors?

Solution.—Substitute in the formula,

$$R = \frac{E}{I} = \frac{5}{20} = 0.25 \text{ ohm}$$

This (0.25 ohm) is the resistance of both wires. Each would have a resistance of 0.125 ohm.

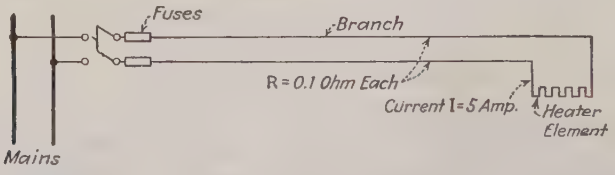


FIG. 24.—Portion of a circuit.

Example.—The electric heater (Fig. 24) takes 5 amp. The resistance of each branch wire is 0.1 ohm. What will be the drop in volts in each branch wire?

Solution.—Substitute in the formula:

$$E = I \times R = 5 \times 0.1 = 0.5 \text{ volt}$$

In both branch wires or in the branch circuit the volts lost would be $2 \times 0.5 = 1$ volt.

Example.—Three motors (Fig. 22) taking respectively 20, 25, and 5 amps. (these values were stamped on the name plates of the motors) are located at the end of a feeder having a resistance of 1.0 ohm on each side. What will be the volts drop in the feeder?

Solution.—Substitute in the formula:

$$E = R \times I = (1 + 1) \times (20 + 25 + 5) = 2 \times 50 = 100 \text{ volts}$$

69. A resistor is an object having resistance; specifically, a resistor is a conductor inserted in a circuit to introduce resistance. A rheostat is a resistor so arranged that its effective resistance can be varied.

70. Resistance to Alternating Current.—The resistance of the conductors of a circuit to alternating current is generally somewhat different from the resistance of the same conductors to direct current (refer to Sec. **112**).

71. The resistances of different materials vary greatly. Some, such as the metals, conduct electricity very readily and hence are called conductors. Others such as wood or slate are, at least when moist, partial conductors. Still others, such as glass, porcelain, and paraffin, are called insulators because they are practically nonconducting. No material is a perfect conductor and no material is a perfect insulator (see Sec. **39**).

72. A circular mil is the area of a circle $\frac{1}{1000}$ in. in diameter. A mil is $\frac{1}{1000}$ of an inch (see Fig. 25). The areas of electric conductors are usually measured in circular mils. Since the area of any figure varies as the square of its similar dimensions, the area of any circle can be expressed in circular mils by squaring its diameter expressed in thousandths. Thus, since $\frac{3}{8} = \frac{375}{1000} = 0.375$, the area of a circle $\frac{3}{8}$ in. in diameter would be $375 \times 375 = 140{,}625$ cir. mils. The area of a circle 0.005 in. in diameter would be $5 \times 5 = 25$ cir. mils.

73. A square mil is the area of a square having sides $\frac{1}{1000}$ in. long (see Fig. 25). Areas of rectangular conductors are sometimes measured in square mils. Areas in square mils are obtained by multiplying together the length and breadth of the rectangle expressed in thousandths of an inch. Thus, the area of a rectangle $\frac{1}{2}$ in. wide and 2 in. long would be $500 \times 2{,}000 = 1{,}000{,}000$ sq. mils. In actual area, a circular mil is about $\frac{8}{10}$ as great as a square mil.

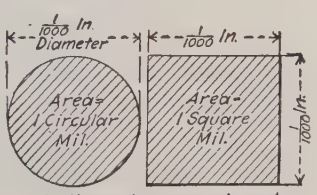


FIG. 25.—Circular mil and square mil.

74. To reduce square mils or square inches to circular mils, or the reverse, apply one of the following formulas or see Sec. **9** for square mil, circular mil, and square inch conversion factors.

$$\text{Sq. mils} = \text{cir. mils} \times 0.7854 \tag{10}$$

$$\text{Cir. mils} = \frac{\text{sq. mils}}{0.7854} \tag{11}$$

$$\text{Cir. mils} = \frac{\text{sq. in.}}{0.0000007854} \tag{12}$$

$$\text{Sq. in.} = \text{cir. mils} \times 0.0000007854 \tag{13}$$

Example.—The sectional area of the bus bar, in Fig. 26, I, is, in circular mils,

$$\text{Cir. mils} = (\text{sq. in.})/(0.0000007854) = (3 \times \tfrac{1}{4}) \div 0.0000007854$$
$$= 0.75 \div 0.0000007854 = 955{,}000 \text{ cir. mils.}$$

Example.—The sectional area of the steel T, shown in Fig. 26, II, in circular mils is:

$$\text{Cir. mils} = \text{sq. in.} \div 0.0000007854 = 0.53 \div 0.0000007854 = 674{,}800 \text{ cir mils.}$$

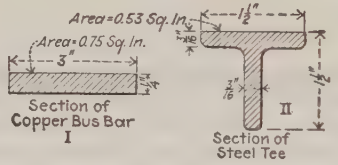


FIG. 26.—Conductor sections.

75. The circular mil-foot (cir. mil-ft.) is the unit conductor. A wire having a sectional area of 1 cir. mil and a length of 1 ft. is a circular mil-foot of conductor. The resistance of a circular mil-foot of a metal is sometimes called its **specific resistance** or its **resistivity.** The resistance of a circular mil-foot of copper under different conditions is given in Fig. 27. Resistances for other metals and alloys are given in Table 80.

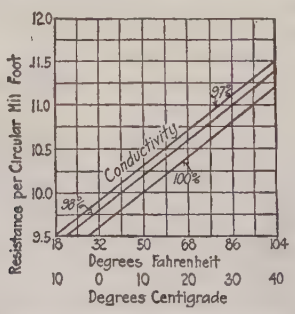


FIG. 27.—Curves showing resistance per circular mil-foot of pure copper at various temperatures and conductivities.

76. To compute the resistance of a conductor of any common metal or alloy use the value given for the resistance of a circular mil-foot of the material in Table 80 in the following formula:

$$R = \frac{p \times l}{\text{cir. mils}} \quad \text{or} \quad \frac{p \times l}{d^2} \tag{14}$$

where R = resistance of the conductor in ohms; p = resistance of a cir. mil-ft. of the material composing the conductor, from Table 80; l =

length of conductor in feet; d = diameter in mils; and d^2 = diameter in mils squared or, what is the same thing, the area of the conductor in circular mils.

The other forms of the formula are:

$$p = \frac{d^2 \times R}{l} \qquad l = \frac{d^2 \times R}{p} \qquad d = \sqrt{\frac{p \times l}{R}} \tag{15}$$

Example.—Taking from Table 80 the resistance of a circular mil-foot of copper at 23°C. (75°F.) as 10.5 ohms, what is the resistance of 500 ft. of copper wire 0.021 in. in diameter?

Solution.—Substituting in the formula:

$$R = \frac{pl}{d^2} = \frac{10.5 \times 500}{21 \times 21} = \frac{5{,}250}{441} = 11.9 \text{ ohms}$$

77. An approximate rule for computing the resistance of round copper wire, in ohms per thousand feet is: Divide 10,500 by the size of the wire in circular mils. This rule should be used only for rough estimating computations.

Example.—Thus, for a 4/0 wire (211,600 cir. mils), the resistance is approximately R = 10,500/211,600 = 0.05 ohm per 1,000 ft.

78. The resistances of conductors that are not circular in section can be computed by first getting their areas in square inches and then reducing this square-inch value to circular mils as indicated above. Then proceed with the formula in the preceding paragraph.

79. Change of Resistance with Change of Temperature.—The resistance of all pure metals increases as they become hot. The resistance of certain alloys is not affected by the temperature. In wiring for light and power, changes in resistance due to changes in temperature are so slight that they may be wholly disregarded. Sometimes, with electrical machinery, changes in resistance due to changes in temperature may be of importance, in that speeds, voltages, or currents may be appreciably affected thereby. The proportion that resistance increases per degree rise in temperature is called the **temperature coefficient of resistance** (see Table 80 for values). For all pure metals, the coefficient is practically the same and is 0.004 for temperatures in degrees centigrade and 0.0023 for temperatures in degrees Fahrenheit.

80. Approximate Specific Resistances and Temperature Coefficients of Metals and Alloys

"Electrical Engineer's Handbook," International Textbook Company

Metal	ρ Resistance of 1 cir. mil-foot in ohms		α Average temperature coefficient per degree C. between 0 and 100°C.	α Average temperature coefficient per degree F. between 32 and 212°F.	Percentage conductivity	Relative resistance
	0°C. or 32°F.	23.8°C. or 75°F.				
Silver, pure annealed	8.831	9.674	0.004000	0.002220	108.60	0.925
Copper, pure annealed	9.390	10.351	0.004280	0.002380	102.10	0.980
Copper, annealed	9.590	10.505	0.004020	0.002230	100.00	1.000
Copper, hard-drawn	9.810	10.745	0.004020	0.002230	97.80	1.022
Gold (99.9 per cent pure)	13.216	14.404	0.003770	0.002090	72.55	1.378
Aluminum (99.5 per cent pure)	15.219	16.758	0.004230	0.002350	63.00	1.587
(Commercial—97.5 per cent pure)	16.031	17.699	0.004350	0.002420	59.80	1.672
Zinc (very pure)	34.595	37.957	0.004060	0.002260	27.72	3.608
Iron, (approx. pure)	54.529	62.643	0.006250	0.003470	17.50	5.714
Iron E.B.B. iron wire	58.702	65.190	0.004630	0.002570	16.20	6.173
Platinum (pure)	65.670	71.418	0.003669	0.002038	14.60	6.845
Iron, B.B. iron wire	68.680	76.270	0.004630	0.002570	13.50	7.407
Nickel	74.128	85.138	0.006220	0.003460	12.94	7.726
Tin (pure)	78.489	86.748	0.004400	0.002450	12.22	8.184
Steel (wire)	81.179	90.150	0.004630	0.002570	11.60	8.621
Substance						
Brass	43.310	.....	.....	.....	22.15	4.515
Phosphor bronze	51.005	.....	0.000640	0.000356	18.80	5.319
Aluminum bronze	73.989	.....	0.001000	0.000556	12.96	7.714
German silver (Cu 50, Zn 35, Ni 15)	127.800	.....	0.000400	0.000220	7.50	17.300
Platinoid [Cu, 59, Zn 25.5, Ni 14, W (tungsten) 55]	251.030	.....	0.000310	0.000172	3.82	26.180
Manganin (Cu 84, Ni 4, Mn 12)	280.790	.....	0.000000	.....	3.41	29.330
Constantan (Cu 58, Ni 41, Mn 1)	{300.77} {312.80}	.....	±0.000010	0.000005	{3.19} {3.07}	{31.35} {32.57}
Gray cast iron	684.000					

81. To find the resistance of a conductor at any ordinary temperature, use this formula:

$$R_h = R_c + [a \times R_c(T_h - T_c)] \quad \text{or} \quad T_h - T_c = \frac{R_h - R_c}{a \times R_c} \quad (16)$$

where R_h = resistance, in ohms, hot; R_c = resistance, in ohms, cold; T_h = temperature of conductor hot, in degrees; T_c = temperature of conductor cold in degrees; and a = the temperature coefficient of the material of the conductor from Table 80. (This is an approximate method, but it is sufficiently accurate for all ordinary work.)

Example.—The resistance of 1 cir. mil-ft. of annealed copper is 9.59 ohms at 32°F. What will its resistance be at 75°F.?

Solution.—From Table 80 the coefficient is 0.00223. Now substitute:

$$R_h = R_c + [a \times R_c(T_h - T_c)] = 9.59 + [0.00223 \times 9.59(75 - 32)]$$
$$= 9.59 + [0.00223 \times 9.59 \times 43] = 9.59 + 0.92 = 10.51 \text{ ohms, at } 75°\text{F.}$$

82. Safe Current Densities for Electrical Contacts and for Cross Sections

Kind of contact	Material	Current density	
		Amp. per sq. in.	Sq. mils per amp.
Sliding contact (brushes)	Copper brush	150– 175	5,700– 6,700
	Brass gauze brush	100– 125	8,000–10,000
	Carbon brush	30– 40	25,000–33,300
Spring contact (switch blades)	Copper on copper	60– 80	12,500–16,700
	Composition on copper	50– 60	16,700–20,000
	Brass on brass	40– 50	20,000–25,000
Screwed contact	Copper to copper	150– 200	5,000– 6,700
	Composition to copper	125– 150	6,700– 8,000
	Composition to composition	100– 125	8,000–10,000
Clamped contact	Copper to copper	100– 125	8,000–10,000
	Composition to copper	75– 100	10,000–13,000
	Composition to composition	70– 90	11,000–14,000
Fitted contact (taper plugs)	Copper to copper	125– 175	5,700– 8,000
	Composition to copper	100– 125	8,000–10,000
	Composition to composition	75– 100	10,000–13,000
Fitted and screwed contact	Copper to copper	200– 250	4,000– 5,000
	Composition to copper	175– 200	5,000– 5,700
	Composition to composition	150– 175	5,700– 6,700
Cross section	Copper wire	1,200–2,000	500– 800
	Copper wire cable	1,000–1,600	600– 1,000
	Copper rod	800–1,200	800– 1,200
	Composition casting	500– 700	1,400– 2,000
	Brass casting	300– 400	2,500– 3,300
	Brass rod	575– 750	1,300– 1,700

83. The temperature rise in a conductor can be determined with the formula of Sec. 81 by measuring hot and cold resistance.—The expression $T_h - T_c$ is the difference between the hot and cold temperature and is therefore the temperature rise or fall.

Example.—The resistance of a set of copper coils measured 20 ohms at a room temperature of 20°C. After carrying current for some time the resistance measured 20.78 ohms. What was the temperature rise in the coil?

Solution.—The temperature coefficient of copper per degree centigrade is, from Table 82, 0.004. Substitute in the formula:

$$T_h - T_c = \frac{R_h - R_c}{aR_c} = (20.78 - 20.0) \div (0.004 \times 20) = 0.78 \div 0.08 = 9.75°\text{C}.$$

Therefore the average temperature rise in the coil was 9¾°C.

84. Contact resistance is the resistance at the point of contact of two conductors. When current flows, heat is always developed at such a point. The greater the clamping pressure between the conductors in contact and the greater the area of contact, the less the contact resistance will be. The nature of the surfaces in contact must also be considered. Smooth surfaces have less contact resistance than do rough surfaces. Contacts should always be so designed that, for a given current, the area of contact will be large enough to prevent the contact resistance from being so great as to cause excessive heating. Table 82 indicates safe values.

85. Work is the overcoming of mechanical resistance through a certain distance. Work is measured by the product of the mechanical resistance times the space through which it is overcome. Work is measured by the product of the moving force times the distance through which the force acts in overcoming the resistance. Work is, therefore, measured in foot-pounds (ft.-lb.).

Example.—What work is done if a weight of 6 lb. is lifted through a distance of 8 ft.?

Solution.—Work = ft. × lb. = 8 × 6 = 48 ft.-lb.

Example.—If 20 gal. of water is pumped to a vertical height of 32 ft., what work has been done?

Solution.—A gallon of water weighs 8 lb. Therefore

$$\text{Work} = \text{ft.} \times \text{lb.} = 32 \times (20 \times 8) = 5{,}120 \text{ ft.-lb.}$$

Example.—If the piston in a steam engine travels 1½ ft. during a certain interval, and the total pressure on the piston is 40,000 lb., what work is done during the interval?

Solution.—Work = ft. × lb. = 1.5 × 40,000 = 60,000 ft.-lb.

86. Power is rate of doing work. The faster work is done the greater the power that will be required to do it. For example, if a 10-hp. motor can raise a loaded elevator a certain distance in 2 min. a 20-hp. motor will (approximately) be required to raise it the same distance in 1 min.

87. The horsepower is the unit of power and is about equal to the power of a strong horse to do work for a short interval. Numerically hp.

is 33,000 ft.-lb. per min. = 550 ft.-lb. per sec. = 1,980,000 ft.-lb. per hr. Expressed as a formula,

$$\text{Hp.} = \frac{L \times W}{33{,}000 \times t} = \frac{\text{ft.-lb. per min.}}{33{,}000} \tag{17}$$

where, hp. = horsepower; L = distance in feet through which W is raised or overcome; W = weight in pounds of the thing lifted or the push or pull in pounds of the force overcome; and t is the time in minutes required to move or overcome the weight W through the distance L.

Fig. 28.—Bucket in shaft.

Example.—What horsepower is required in raising the load and bucket weighing 200 lb., shown in Fig. 28, from the bottom to the top of the shaft, a distance of 100 ft., in 2 min.?

Solution.—Substitute in the formula:

$$\text{Hp.} = \frac{L \times W}{33{,}000 \times t} = \frac{100 \times 200}{33{,}000 \times 2} = 0.3 \text{ hp.}$$

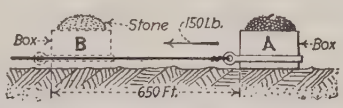


Fig. 29.—Moving loaded box.

Example.—What average horsepower is required while moving the box loaded with stone, in Fig. 29, from A to B, 650 ft., in 3 min.? It takes a horizontal pull of 150 lb. to move the box.

Solution.—Substitute in the formula:

$$\text{Hp.} = \frac{L \times W}{33{,}000 \times t} = \frac{650 \times 150}{33{,}000 \times 3} = 0.98 \text{ hp.}$$

88. Electric power is the rate of doing electrical work. The unit is the watt or kilowatt. A kilowatt is 1,000 watts. Work is being done at the rate of 1 watt when a constant current of 1 amp. is maintained through a resistance by an e.m.f. of 1 volt.

89. To Reduce Horsepower to Watts and Kilowatts and Vice Versa.—One horsepower equals 746 watts, therefore

$$\text{Hp.} = \frac{\text{watts}}{746} = \text{watts} \times 0.00134$$

$$\text{Watts} = \text{hp.} \times 746 \tag{18}$$

$$\text{Hp.} = \frac{\text{kw.}}{0.746} = \text{kw.} \times 1.34$$

$$\text{Kw.} = \text{hp.} \times 0.746. \tag{19}$$

Example.—Watts = 2,460; hp. = ?
Solution.—Substitute in formula:

$$\text{Hp.} = \frac{\text{watts}}{746} = 2{,}460 \div 746 = 3.3 \text{ hp.}$$

Example.—A motor takes 30 kw. How many horsepower is it taking?
Solution.—Substitute in the formula:

$$\text{Hp.} = \frac{\text{kw.}}{0.746} = 30 \div 0.746 = 40.24 \text{ hp.}$$

Or instead, using the other formula:

$$\text{Hp.} = \text{kw.} \times 1.34 = 30 \times 1.34 = 40.2 \text{ hp.}$$

90. Power in d-c circuits is equal to the product of volts and amperes. Expressing this as a formula

$$P = I \times E \qquad I = \frac{P}{E} \qquad E = \frac{P}{I} \tag{20}$$

and also in circuits where all the energy is converted into heat energy

$$P = I^2 \times R \qquad P = \frac{E^2}{R} \qquad I = \sqrt{\frac{P}{R}} \qquad E = \sqrt{R \times P} \tag{21}$$

$$R = \frac{E^2}{P} \qquad R = \frac{P}{I^2} \tag{22}$$

where I = current in amperes; E = voltage or e.m.f. in volts; R = resistance in ohms; and P = power in watts.

91. In applying the above equations be careful that the values of current, voltage, and resistance used in any one problem all apply to the same circuit or to the same portion of a circuit.

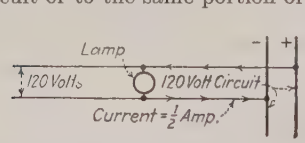


FIG. 30.—Incandescent lamp branch circuit.

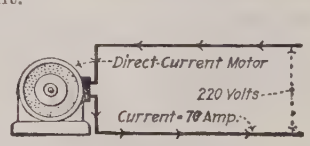


FIG. 31.—Electric motor.

Example.—How many watts are consumed by the incandescent lamp in Fig. 30?
Solution.—Substitute in the formula:

$$P = I \times E = \tfrac{1}{2} \times 120 = 60 \text{ watts}$$

Example.—How many watts are taken by the motor of Fig. 31? How many kilowatts? How many horsepower?
Solution.—Substitute in the formula:

$$P = I \times E = 70 \times 220 = 15{,}400 \text{ watts}$$

$$\text{Kw.} = \frac{\text{watts}}{1{,}000} = \frac{15{,}400}{1{,}000} = 15.4 \text{ kw.}$$

$$\text{Hp.} = \frac{\text{watts}}{746} = \frac{15{,}400}{746} = 20.6 \text{ hp.}$$

Example.—In the feeder of Fig. 32, what amount of power will be lost in the line wires to the motor?

Solution.—Substitute in the formula:

$$P = I^2 \times R = (40 \times 40) \times (0.3 + 0.3) = 1.600 \times 0.6 = 960 \text{ watts}$$

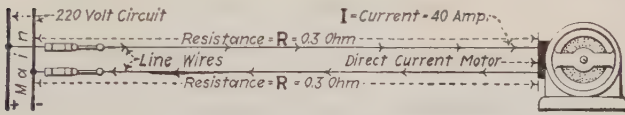


FIG. 32.—Feeder.

92. Power in A-c Circuits.—The power of an a-c circuit is very seldom equal to the direct product of the volts and amperes. In order to calculate the power of a single-phase a-c circuit, the product of the volts and amperes must be multiplied by a certain factor called the power factor (see Sec. **129**).

93. Energy is capacity for doing work. Any body or medium which is of itself capable of doing work is said to possess energy. A coiled clock spring possesses energy because, in unwinding, it can do work. A moving projectile possesses energy because it can overcome the resistance offered by the air, by armor plate, etc., and thus do work. A charged storage battery possesses energy because it can furnish electricity to operate a motor. Energy can be expressed in foot-pounds.

94. Energy of one sort may be transformed into energy of another sort. Heat energy in coal may be transformed (with a certain loss), with a boiler, a steam engine, and a generator, into electrical energy. The energy possessed by a stream of falling water may be transformed, with a water wheel and generator, into electrical energy. There is a definite numerical relation between different sorts of energy. Thus 1 B.t.u., the unit of heat energy = 778 ft.-lb. In electrical units, energy is expressed in watt-hours or kilowatt-hours.

95. A kilowatt-hour represents the energy expended if work is done for 1 hr. at the rate of 1 kw.

96. A horsepower-hour represents the energy expended if work is done for 1 hr. at the rate of 1 hp. One horsepower-hour therefore equals $60 \times 33{,}000 = 1{,}980{,}000$ ft.-lb.

97. Efficiency is the name given to the ratio of output to input. No machine gives out as much useful energy or power as is put into it. There are some losses in even the most perfectly constructed machines. Efficiency is usually expressed as a percentage, thus, "the efficiency of a certain motor is 80 per cent." This means that only 80 per cent of the energy or power received by the motor as electricity is delivered by the motor at the pulley. Another way of stating the definition is

$$\text{Efficiency} = \frac{\text{output}}{\text{input}} \qquad (23)$$

It follows that

$$\text{Input} = \frac{\text{output}}{\text{efficiency}} \tag{24}$$

and

$$\text{Output} = \text{input} \times \text{efficiency} \tag{25}$$

When using the formulas, output and input must be expressed in the same units.

98. Output is the useful energy delivered by a machine, and **input** is the energy supplied to a machine.

Example.—If 45 kw. is supplied to a motor and its output is found to be 54.2 hp., what is its efficiency?

Solution.—Since 1 hp. = 0.746 kw., 54.2 hp. = 54.2 × 0.75 = 40.6 kw. Then, substituting in the formula,

$$\text{Efficiency} = \frac{\text{output}}{\text{input}} = \frac{40.6}{45} = 0.90 = 90 \text{ per cent}$$

99. Torque is the measure of the tendency of a body to rotate. It is the measure of a turning or twisting effort and is usually expressed in pounds feet or in pounds force at a given radius. Torque is expressed as the product of the force tending to produce rotation times the distance from the center of rotation to the point of application of the force. Thus in Fig. 33 there is a torque of 50 × 1 = 50 lb.-ft. tending to turn the windlass due to the weight attached to the rope. In the motor of Fig. 34 the group of conductors under the north pole produces a combined force of 10 lb. The torque produced by this group of conductors will be $10 \times \frac{9}{12} = 7.5$ lb.-ft. The group of conductors under the south pole will similarly produce $10 \times \frac{9}{12} = 7.5$ lb.-ft. Both of these torques tend to produce rotation in the same direction. Therefore, the total torque produced by the motor will be 7.5 + 7.5 = 15 lb.-ft.

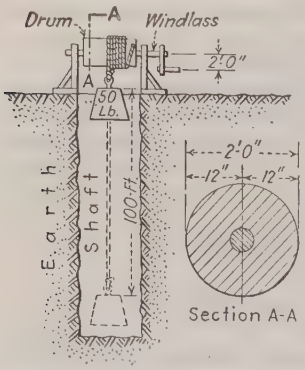


FIG. 33.—Example of work and of torque.

Torque exists even if there is no motion. Thus, in Fig. 33 the torque exerted by the weight is 50 lb.-ft. so long as the weight is supported, whether the drum is moving or standing still. In the motor of Fig. 34 a torque of 15 lb.-ft. is exerted upon the armature tending to produce rotation, whether the motor is revolving or standing still. If there is no rotation, no work can be done, yet there is torque tending to produce rotation.

100. Relation between Horsepower and Torque.

$$\text{Hp.} = \frac{6.28 \times \text{r.p.m.} \times T}{33{,}000} \tag{26}$$

or

$$T = \frac{33{,}000 \text{ hp.}}{6.28 \times \text{r.p.m.}} \tag{27}$$

where T = torque in lb.-ft.

Example.—What is the torque of a 10-hp. motor if delivering full load at 1,150 r.p.m.?

$$T = \frac{33{,}000 \times 10}{6.28 \times 1{,}150} = 45.7 \text{ lb.-ft.}$$

101. Torque and Force Relations in Mechanisms.—In any mechanism such as the windlass of Fig. 33, or a motor belted or geared to a load, if the losses are neglected so that the efficiency is 100 per cent, the power output will be equal to the power input. For such a perfect mechanism the following relations will hold true:

$$T_1 \times \text{r.p.m.}_1 = T_2 \times \text{r.p.m.}_2 \tag{28}$$

or

$$\frac{T_1}{T_2} = \frac{\text{r.p.m.}_2}{\text{r.p.m.}_1}$$

where T_1 = torque at point 1 in the mechanism; r.p.m.$_1$ = r.p.m. at point 1 in the mechanism; T_2 = torque at point 2 in the mechanism; and r.p.m.$_2$ = r.p.m. at point 2 in the mechanism.

In the windlass of Fig. 33 the r.p.m. for all points in the mechanism are the same. Therefore the torque at any point is equal to the torque at any other point. The torque that must be exerted at the handle of the windlass in order to raise the weight at a uniform rate of speed would have to be equal to the torque exerted by the weight. This is neglecting the weight of the rope and the friction. The force that must be exerted on the handle will be $50\frac{1}{2} = 25$ lb.

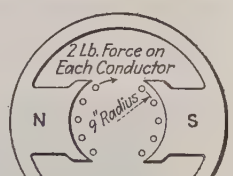


FIG. 34.—Torque produced by the force on the conductors of a motor.

The motor of Fig. 34 is equipped with a pulley on the shaft for driving a belt. The pulley has a diameter of 6 in. The force exerted upon the belt (the tension of the belt) would be determined in the following manner: Since the r.p.m. of the pulley is the same as the r.p.m. of the motor armature, the torque produced by the conductors is the same as the torque exerted by the pulley. The force on the belt is therefore $15/0.5 = 30$ lb.

102. Wave Form of Alternating Currents and Voltages.—An alternating current or voltage is one which is reversed at regular intervals. The curve formed by plotting the instantaneous values of the voltage or current against time is called the wave form of the voltage or current. It is best to have the value of an alternating current or voltage vary with time according to what is known as the sine law. The instantaneous

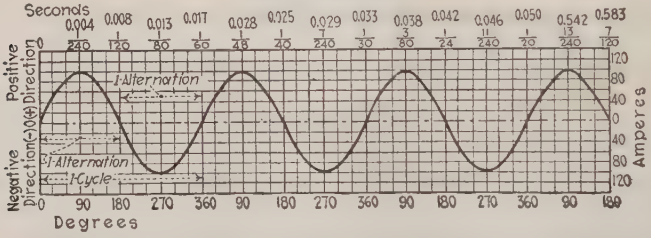


FIG. 35.—Graph of a 60-cycle alternating current having a maximum value of 100 amp.

values of an alternating current varying according to this law are shown in Fig. 35. A voltage or current which varies in this manner is called a sinusoidal voltage or current. Most modern a-c generators produce a voltage which is very nearly sinusoidal and are generally so considered. The current in some a-c circuits will be very nearly sinusoidal and in others may differ considerably from the sine law. In most cases, however, for practical work both alternating voltages and currents can be considered as following the sine law. For cases where it is not satisfactory to do this, the calculations become quite complicated, and a discussion of them is outside the scope of this book.

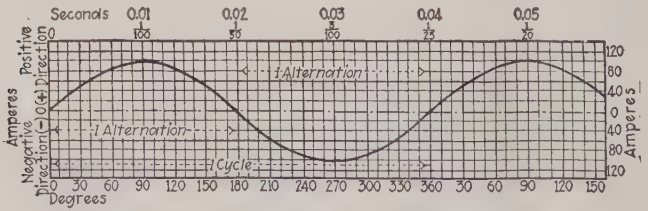


FIG. 36.—Curve of a 25-cycle alternating current.

103. A cycle is a complete set of values through which an *alternating current* (see previous Sec. **34** for explanation of "Alternating Current") repeatedly passes (see Fig. 35). The expression "60 cycles per second" means that the current referred to makes 60 complete cycles in a second. It therefore requires $\frac{1}{60}$ sec. to complete 1 cycle. See Fig. 35. With a 25-cycle current, $\frac{1}{25}$ sec. is required to complete 1 cycle. See Fig. 36.

104. The frequency of an alternating current is the number of cycles completed in 1 sec. A frequency of 60 cycles is practically standard for lighting and power installations. Most electric power companies generate, transmit, and distribute their power at this frequency. For railroad electrification, 25 cycles is sometimes employed. If 25 cycles is used for lighting, there will be flickering of the lamps. Some of the older stations in this country still generate at 50 cycles. In Europe 50 cycles has commonly been used for light and power and 16⅔ cycles for railroad electrification.

105. Electrical Degrees.—The instantaneous values of an a-c voltage can be studied from Fig. 37, which shows an elementary four-pole generator and the wave form of voltage for one complete revolution of the conductor. When the conductor is in the position marked *A*, halfway between adjacent poles, it will not be cutting any flux and therefore there will be no voltage induced in the conductor. As the conductor moves from this position, it will start to cut flux and will cut flux at a greater and greater rate until the conductor is in the position *B*. At this point, flux will be cut at the maximum rate, and the voltage produced will be maximum. As the conductor moves from position *B* to position *C*, it will cut flux at a decreasing rate, until, when position *C* is reached (half way between poles), the conductor will not be cutting flux at all. As the conductor moves on from position *C*, it will start to cut flux, but the direction of the flux is reversed. The direction of the induced voltage will therefore reverse at the instant when the conductor passes through position *C*. Pursuing the same reasoning for the rest of the revolution, the voltage produced in the conductor will follow the wave form shown in Fig. 37. The arc that the conductor must pass through in order to generate one complete cycle of voltage is called 360 electrical degrees. In any a-c generator there are therefore 360 electrical degrees in the arc between the center line of one pole and the center line of the next pole of the same polarity. The number of electrical degrees in one complete revolution for any generator is equal to 360 times the number of pairs of

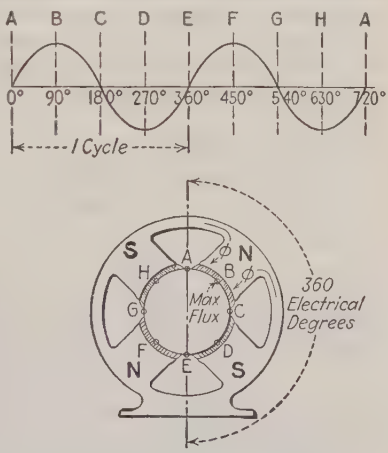


FIG. 37.—Elementary a-c generator, illustrating electrical degrees and wave form.

poles for which the machine is wound. One electrical degree is equal to 1/(pair of poles) part of a mechanical degree.

If the elementary generator of Fig. 37 was producing a 60-cycle voltage, the conductor would have to make 1,800 r.p.m. This would mean that the conductor makes 1 revolution in $^{60}/_{1800}$ or $1/30$ sec. Since the voltage goes through 2 cycles in 1 revolution (see Fig. 37), it takes $1/60$ sec. for 1 cycle. This means that in $1/60$ sec. the conductor moves from position *A* to position *E*.

Refer to Fig. 37 and take *A* position as zero instant of time and as zero electrical degrees. When the conductor has moved from position *A* to *B*, it will have passed through $^{360}/_{4}$ or 90 electrical degrees, and the elasped time will be $1/4 \times 60$ or $1/240$ sec. Electrical degrees and time are therefore proportional. Therefore instead of plotting the instantaneous values of the voltage against time, they can be plotted against electrical degrees. These two methods of plotting such curves are shown in Figs. 35 and 36.

106. The word phase, when properly used in a-c terminology, refers to time. When two alternating currents are in phase, they reach their

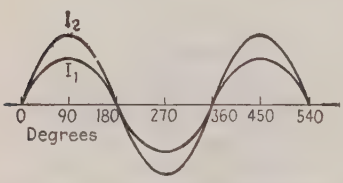


FIG. 38.—Two alternating currents in phase.

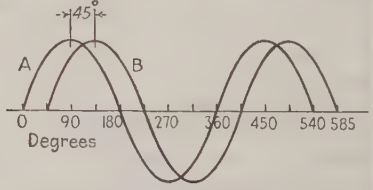


FIG. 39.—Two alternating currents out of phase.

corresponding zero, maximum, and intermediate values at exactly the same instants. Two in-phase a-c quantities are shown in Fig. 38. If currents or voltages are not in phase, they reach corresponding values at different instants of time, as shown in Fig. 39. Since electrical degrees are proportional to time, it is standard practice to state the out-of-phase relation of two quantities in electrical degrees. In specifying the phase relation of two quantities, it is necessary to state whether it is a leading or lagging relationship. For example, referring to Fig. 39, it is not complete to state that quantity *A* is 45 degrees out of phase with *B*. The correct statement is either "*A* leads *B* by 45 degrees," or "*B* lags *A* by 45 degrees." The number of degrees that two quantities are out of phase is the number of electrical degrees that must elapse in the time between the occurrence of a certain instantaneous value of one quantity and the occurrence of the corresponding instantaneous value of the other quantity. For example, referring to Fig. 39, quantity *B* does not reach its maximum positive value until 45 degrees after quantity *A* has reached its maximum positive value. Quantity *B*, therefore, lags quantity *A*

by 45 degrees. The number of electrical degrees that two quantities are out of phase is called the phase angle.

107. A three-phase current consists of three different alternating currents out of phase 120 degrees with each other. A **two-phase current** consists of two different alternating currents out of phase 90 degrees with each other.

Sometimes each of the three wires of a three-phase circuit is called a phase wire or, for short, a phase. Also, any pair of wires of a polyphase circuit across which the normal voltage of the circuit should exist is sometimes referred to as a phase of the circuit.

108. The maximum value of an alternating current or voltage is the greatest value that it attains. This is an instantaneous value (see Fig. 40).

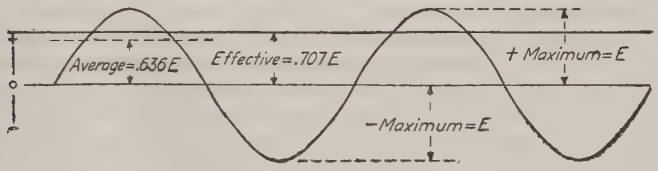


FIG. 40.—Alternating e.m.f. values.

109. The so-called average value of an alternating current or voltage is the average of the instantaneous values for ½ cycle. Average values are not of much value to the practical man.

110. Effective values of alternating current and voltage are the ones ordinarily referred to when speaking of alternating quantities. Alternating voltages and currents are constantly changing in value, within a certain range, from instant to instant even if the load is constant. It is not practicable to deal with or indicate with instruments these constantly changing values. The effective value of an alternating current or voltage is the value of a direct current or voltage that will have the same heating effect. A sinusoidal alternating current which has a maximum value of 14.14 amp. will have the same heating effect as a 10-amp. direct current. The effective value of the alternating current is therefore 10 amp. The practical man deals almost exclusively with effective values. Measuring instruments indicate effective values. The relation between effective and maximum values for sinusoidal quantities is given below and illustrated in Fig. 40

$$\text{Effective value} = 0.707 \times \text{maximum value} \tag{29}$$

$$\text{Maximum value} = \frac{\text{effective value}}{0.707} \tag{30}$$

Example.—What is the effective voltage of a circuit that has a maximum voltage of 156?

Solution.—Substitute in the formula:

$$\text{Effective value} = 0.707 \times \text{maximum value} = 0.707 \times 156 = 110 \text{ volts}$$

Example.—If a voltmeter on an a-c circuit reads 2,200, what is the maximum instantaneous voltage?

Solution.—Substitute in the formula:

$$\text{Maximum value} = \frac{\text{effective value}}{0.707} = \frac{2,200}{0.707} = 3,110 \text{ volts}$$

111. Characteristics of Circuits.—In constant-current d-c circuits there is only one characteristic of the circuit that affects the value of the current, *i.e.*, the resistance offered by the material of which the circuit is made. In all other cases there are three characteristics of a circuit that affect the value of current that will flow through it, namely, resistance, inductance, and capacity.

112. Resistance of A-c Circuits.—As mentioned in Sec. **70** the resistance of a circuit to alternating current may be considerably different from its resistance to direct current. This increase in the resistance may be due to two factors. One of these factors takes place inside the conductors. It is called skin effect and is discussed in the following sections. The other factor is due to the proximity of magnetic and electrical conducting material to the circuit. The varying magnetic field produced by the alternating current results in electric and magnetic power losses in these neighboring materials. These power losses must be supplied by the power delivered to the electric circuit and therefore result in increasing the effective resistance of the circuit over what it was for direct current. Refer to Sec. **150** for example of effective resistance to an alternating current.

113. Skin Effect.—When an alternating current flows through a conductor, there is an inductive action whereby the current in the conductor is forced toward its surface. The current density is greater at the surface than at the center, and under certain conditions there may be practically no current flowing along the axis of the conductor. Although skin effect and self-induction both originate from the same magnetic field, they are not otherwise related. Since it increases voltage drop and energy loss, skin effect amounts to an increase in resistance and is so considered. Table 49 of Div. 11 gives values by which actual resistances of conductors must be multiplied to obtain their virtual resistances to alternating currents. Nonconducting cores are sometimes placed in the centers of large cables for alternating currents so that all the metal will be worked at the best possible efficiency (see Div. 2 for such conductors).

114. Skin effect in conductors of magnetic materials is much greater than in those of nonmagnetic materials owing to the stronger magnetic field that a given current will set up in a magnetic metal (see the tables in the "Standard Handbook for Electrical Engineers").

115. Skin effect in stranded conductors is, for all practical purposes, equal to that in solid conductors of equal diameters.

Example.—A 400,000-cir.-mil wire 1,000 ft. long has an actual resistance of 0.02684 ohm. Its resistance to a 60-cycle alternating current would be $0.02684 \times 1.011 = 0.0271$ ohm.

116. Self-induction is the phenomenon whereby an e.m.f. is induced in a conductor by a change of current in the conductor itself. This e.m.f. is always in such a direction that it opposes the change of current which produces it.

Whenever current passes through a conductor, it tends to set up a magnetic field around the conductor. If the current through the conductor changes, the flux produced by it will change. The change in the flux will produce a voltage in the conductor. This voltage is the voltage of self-induction. Since inductance has an effect only when the current in the conductor is changing, inductance will have no effect on a closed d-c circuit but will have an effect in a-c circuits where the current is always changing from instant to instant.

The effect of inductance in an a-c circuit is that it produces opposition to the flow of the current and tends to make the current lag behind the voltage in time or phase. If a pure inductive circuit (one with only inductance, no resistance) could be built, the current would lag 90 degrees or ¼ cycle behind the voltage. In actual circuits containing both resistance and inductance, the current will lag some angle between 0 and 90 degrees behind the voltage. The angle of lag will depend upon the relative value of the resistance and inductance.

117. Inductance of a circuit is measured in a unit called henrys. It is expressed by the symbol L. A circuit has an inductance of 1 henry when, if the current is changed at the rate of 1 amp. per sec., 1 volt is induced in the circuit thereby.

118. Inductive reactance is the name given to the opposition to the flow of changing current due to inductance. It is measured in ohms the same as resistance. Reactance and resistance are both opposition to the flow of current but otherwise are entirely different quantities. Inductive reactance is designated by the symbol X_L. For a sinusoidal current the value of the inductive reactance is

$$X_L = 2\pi fL \tag{31}$$

where X_L = inductive reactance in ohms; f = frequency in cycles per second; and L = inductance in henrys.

119. The angle of lag of a current in an inductive circuit can be calculated from the following equation:

$$\text{Tangent of angle of lag} = \frac{X_L}{R} \tag{32}$$

where X_L = inductive reactance in ohms: and R = a-c resistance (not d-c resistance). Also see method of Sec. **127.**

120. Capacity or capacitance is the phenomenon whereby a circuit stores electrical energy. Whenever two conducting materials are separated by an insulating material, they have this ability of storing electrical energy. Such an arrangement of materials (two conductors separated by an insulator) is called a condenser or capacitor. If a source of d-c voltage is connected between the two conducting materials of a condenser, a current will flow for a certain length of time. The initial current will be relatively large but will rapidly diminish to zero. A certain amount of electrical energy will then be stored in the condenser. If the source of voltage is removed and the conductors of the condenser are connected to the two ends of a resistor, a current will then flow from the condenser through the resistor for a certain length of time. The initial current will be relatively large but will rapidly diminish to zero. The direction of the current will be opposite to the direction of the current when the condenser was being charged by the d-c source. When the current reaches zero, the condenser will have dissipated the energy which was stored in it as heat energy in the resistor. The condenser will then be said to be discharged.

121. The farad is the unit of capacity. It is designated by the symbol C. A circuit or condenser will have a capacity of 1 farad if, when the voltage across it is increased 1 volt, its stored electricity is increased by 1 coulomb. Another definition for a capacity of 1 farad, which results in the same effect, is given below. A circuit or condenser will have a capacity of 1 farad when, if the voltage impressed upon it is changed at the rate of 1 volt per sec., 1 amp. of charging current flows.

122. Capacity in A-c Circuits.—From the above discussion it is seen that a condenser has a sustained current only as long as the voltage is changing. A condenser connected to a d-c supply will not have a sustained current. In an a-c circuit, the voltage is continually changing from instant to instant. Therefore, when a condenser is connected to an a-c supply, an alternating current continues to flow. The current is first in one direction, charging the condenser, and then in the opposite direction discharging the condenser.

The effect of capacity in an a-c circuit is that it produces opposition to the flow of the current and tends to make the current lead the voltage. For a pure capacity circuit (one with only capacity, no resistance) the current would lead the voltage by 90 degrees or ¼ cycle. For a circuit with both resistance and capacity, the current will lead the voltage by some angle between 0 and 90 degrees, depending upon the relative value of the resistance and the capacity.

123. Capacitive reactance is the name given to the opposition to the flow of alternating current due to capacity. It is measured in ohms the same as resistance and inductive reactance. Capacitive reactance is

designated by the symbol X_C. For a sinusoidal impressed voltage the value of the capacitive reactance is

$$X_C = \frac{1}{2\pi fc} \tag{33}$$

where X_L = capacitive reactance in ohms; f = frequency in cycles per second; and C = capacity in farads.

124. The angle of lead of a current in a capacitive circuit can be calculated from the following equation:

$$\text{Tangent of angle of lead} = \frac{X_C}{R} \tag{34}$$

where X_C = capacitive reactance in ohms; and R = a-c resistance (not d-c resistance).

Also see method of Sec. **127.**

125. Impedance is the name given to the total opposition to the flow of alternating current. It is the combined opposition of resistance, inductive reactance, and capacitive reactance. Impedance is measured in ohms and is expressed by the symbol Z. The impedance of a series circuit may be calculated by the following formulas:

For a circuit containing resistance, inductance, and capacity

$$Z = \sqrt{R^2 + (X_L - X_C)^2} \tag{35}$$

For a circuit containing resistance and inductance

$$Z = \sqrt{R^2 + X_L{}^2} \tag{36}$$

For a circuit containing resistance and capacity

$$Z = \sqrt{R^2 + X_C{}^2} \tag{37}$$

For a circuit containing only resistance

$$Z = R \tag{38}$$

For a circuit containing only inductance

$$Z = X_L \tag{39}$$

For a circuit containing only capacity

$$Z = X_C \tag{40}$$

where Z = impedance in ohms; X_L = inductive reactance in ohms; and X_C = capacitive reactance in ohms.

126. Relations between voltage, current, and impedance are

$$E = IZ \tag{41}$$

$$I = \frac{E}{Z} \tag{42}$$

$$Z = \frac{E}{I} \tag{43}$$

where E = voltage impressed on circuit in volts; I = current in amperes; and Z = impedance in ohms.

It is noticed that Ohm's law (Sec. **63**) cannot be used for a complete a-c circuit unless the circuit contains only resistance. The same general precautions should be observed in using the above formulas for a-c circuits as were given for Ohm's law in Sec. **67**. The above equations will apply to a whole circuit or to part of a circuit.

127. The phase angle of a circuit containing resistance, inductance, and capacity can be found from the following formula:

$$\text{Cosine of phase angle} = \frac{R}{Z} \tag{44}$$

where Z = impedance in ohms; and R = resistance in ohms.

128. Apparent power is the term applied to the product of voltage and current in an a-c circuit. It is expressed in volt-amperes (va.) or in kilovolt-amperes (kva.).

129. Power factor is the ratio of the true power or watts to the apparent power or volt-amperes. The power factor is expressed as a decimal or in percentage. Thus power factors of 0.8 or of 80 per cent are the same. In giving the power factor of a circuit, it should be stated whether it is leading or lagging. The current is always taken with respect to the voltage. A power factor of 0.75 lagging means that the current lags the voltage. The power factor may have a value anywhere between 0 and 1.0 but can never be greater than 1.0

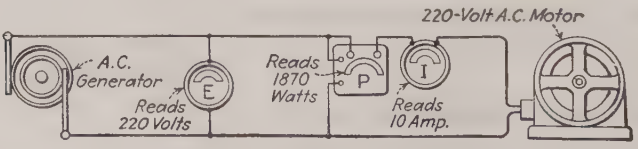


FIG. 41.—Example of power factor.

Example.—In Fig. 41, which shows a single-phase circuit, the ammeter I reads 10 amp. and the voltmeter E, 220 volts. The apparent power is the product of volts and amperes or $IE = 10 \times 220 = 2{,}200$ volt-amperes. But the wattmeter P reads 1,870 watts. A wattmeter always indicates real or true power. Therefore the power factor (for a single-phase circuit) is

$$\text{Power factor} = \frac{\text{true watts}}{\text{apparent power}} = \frac{1{,}870}{2{,}200} = 0.85 \text{ or } 85 \text{ per cent}$$

130. The cosine of the angle of lag or lead is equal to the power factor. Cosines for different angles can be found in triogonometric tables in handbooks (see Sec. 1). The symbol θ, a Greek letter, pronounced theta, is often used to designate the angle of lag or lead; hence power factor is sometimes referred to as cos θ (cosine theta). This means the cosine of the angle θ.

131. The power factor in a noninductive circuit, one containing resistance only, is always 1, or 100 per cent, *i.e.*, the product of volts and amperes in such a circuit gives true power.

132. The power factor in a circuit containing inductance or capacity may be anything between 0 and 1 (0 and 100 per cent), depending on the amount of inductance or capacity in the circuit.

133. Typical power factors of various kinds of central-station loads are as follows:

Incandescent Lighting.—1.0.

Incandescent Lighting with Small Stepdown Transformers.—0.95 to 0.98.

Incandescent Street-lighting Series Circuits.—0.6 to 0.8.

Sodium-vapor Street Lighting, Parallel Circuits.—0.8 to 0.85.

Sodium-vapor Street Lighting, Series Circuits.—0.5 to 0.7.

Fluorescent Lighting.—Depends on type of auxiliary used, 0.5 to 0.95.

Mercury-vapor Lighting.—Depends on type of auxiliary used, 0.5 to 0.95.

Single-phase Induction Motors, Squirrel-cage Rotor.—$\frac{1}{20}$ to 1 hp., power factor, 0.55 to 0.75, average 0.68 at rated load; 1 to 10 hp., power factor, 0.75 to 0.86, average 0.82, at rated load.

Polyphase Induction Motors, Squirrel-cage Rotor.—1 to 10 hp., power factor, 0.75 to 0.91, average 0.85 at rated load; 10 to 50 hp., power factor, 0.85 to 0.92, average 0.89. at rated load.

Polyphase Induction Motors, Phase-wound Rotors.—5 to 20 hp., power factor, 0.80 to 0.89, average 0.86 at rated load; 20 to 100 hp., power factor, 0.82 to 0.90, average 0.87 at rated load.

Induction Motor Loads in General.—Power factor from 0.60 to 0.85, depending on whether motors are carrying their rated loads.

Rotary Converters, Compound Wound.—Power factor at full load can be adjusted to practically 100 per cent. At light loads it will be lagging, and at overloads slightly leading.

Rotary Converters, Shunt Wound.—The power factor can be adjusted to any desired value and will be fairly constant at all loads with the same field rheostat adjustment. Rotary converters, however, should not be operated below 0.95 power factor leading or lagging at full load or overload.

Small Heating Apparatus.—This load has the same characteristics as an incandescent-lightning load. The power factor of the load unit is

practically unity, but the distributing transformers will lower it to some extent.

Arc Furnaces.—Power factor 0.80 to 0.90.

Induction Furnaces.—Power factor 0.60 to 0.70.

Electric-welding Transformers.—Power factor 0.50 to 0.70.

Synchronous Motors.—Adjustment between 0.80 power factor leading to unity power factor. (1) Operating power factors above 0.95 will be obtained only when practically all the load is synchronous motors or converters which may be operated at practically unity power factor. (2) Power factors of 0.90 to 0.95 can be safely predicted only when the load is entirely incandescent lighting or heating, or if a large noninductive load, such as synchronous motors or converters, is used with a smaller proportion of inductive motor load. (3) For the average central-station load, consisting of lighting and motor service, a power factor of 0.80 should be assumed. (4) A power factor of 0.70 should be assumed for a plant having a large proportion of induction motors, fluorescent lighting, electric furnaces, or electric welding load.

134. Kilowatts and Kilovolt-amperes (General Electric Company).—The term kilowatt (kw.) indicates the measure of power which is all available for work. Kilovolt-amperes (kva.) indicate the measure of apparent electrical power made up of two components, an energy component and a wattless or induction component. Kilowatts indicate real power and kilovolt-amperes apparent power. They are identical only when current and voltage are in phase, *i.e.*, when the power factor is 1. Ammeters and voltmeters indicate total effective current and voltage regardless of the power factor, while a wattmeter indicates the effective product of the instantaneous values of e.m.f. and current. A wattmeter, then, indicates real power.

Standard guaranties on a-c generators are made on the basis of loads at 80 per cent power factor. However, it must not be inferred that a given generator will deliver its rated power output at all power factors. The generator rating in kilowatts will be reduced in proportion to the power factor and probably in a greater ratio if the power factor is very low. The method of rating a-c generators by kilovolt-amperes instead of by kilowatts is now in general use.

In discussing an a-c load, it is well to state it in terms of kilowatts, power factor, and kilovolt-amperes, thus: 200 kw., 80 per cent power factor (250 kva.). This shows that the current in the circuit corresponds to 250 kva. and heats the generator and conductors to that extent, but that only 200 kw. is available for doing work. An illustration of the distinction between kilowatts and kilovolt-amperes is given in Fig. 42.

135. Effects of Low Power Factor.—It is sometimes considered that the wattless component of a current at low power factor is circulated without an increase of mechanical input over that necessary for actual power requirements. This is inaccurate because internal work or losses due to

this extra current are produced and must be supplied by the prime mover. Since these extra losses manifest themselves in heat, the capacity of the machine is reduced. Also wattless components of current heat the line conductors, just as do energy components, and cause losses in them. The loss in any conductor is always (see Sec. **90**)

$$P = I^2R \qquad (45)$$

where P = the loss in watts; I = the current in amperes in the conductor; and

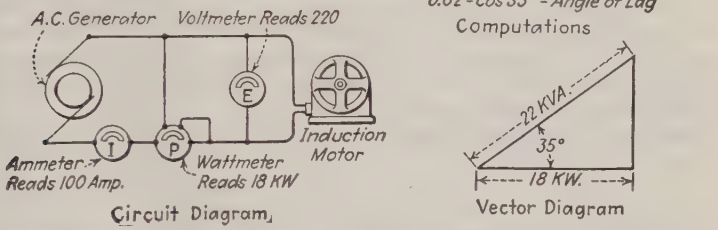


FIG. 42.—Illustrating the distinction between kilowatts and kilovolt-amperes

R = the resistance in ohms. It requires much larger equipment and conductors to deliver a certain amount of power at a low power factor than at a power factor close to unity.

136. Correction of Low Power Factor.—In industrial plants, excessively low power factor is usually due to underloaded induction motors because the power factor of motors is much less at partial loads than at full load. Where motors are underloaded new motors of smaller capacity should be substituted (see Induction Motors, Index). Power factor can be corrected by installing synchronous motors (see Index) which, when overexcited, have the property of neutralizing the wattless or reactive components of currents or by connecting static condensers across the line.

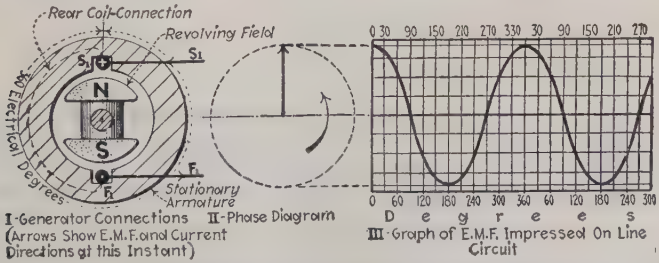


FIG. 43.—Elementary two-pole single-phase a-c generator.

137. A single-phase alternating e.m.f. will be induced in an armature coil which (S_1 and F_1, Fig. 43) has its sides set, in a generator frame, the

same distance apart as are a north and a south magnet which are forced to sweep continuously past the coil sides at a uniform speed. The distance between a north and a south pole is always called 180 electrical degrees. The distance between a north and the next north pole is called 360 electrical degrees. In any given generator, the circumferential distance is the same between any two adjacent north and south poles.

138. In actual a-c single-phase generators, there are a number of pairs of north and south poles arranged on a revolving-field structure. There is a corresponding number of coils arranged around the frame, each having its sides set approximately 180 electrical degrees apart. Then, the coils are connected in series so that their e.m.fs. will be additive. The combination of their e.m.fs. is the voltage which is impressed by the generator on the circuit. Some small revolving-armature a-c generators have rotating armatures and stationary fields, but their principle is the same as that of the revolving-field machines.

139. For a single-phase circuit the relations between kilowatt and kilovolt-amperes are

$$\text{Kilovolt-amperes} = \frac{\text{volts} \times \text{amperes}}{1{,}000} \quad \text{or} \quad \text{Kva.} = \frac{E \times I}{1{,}000} \tag{46}$$

$$\text{Kw.} = \text{kva.} \times \text{power factor} \qquad \text{Kva.} = \frac{\text{kw.}}{\text{power factor}} \tag{47}$$

$$\text{Power factor} = \frac{\text{kw.}}{\text{kva.}} \tag{48}$$

For an example see Fig. 42.

140. For a single-phase circuit, the following equations show the relations between power, current, voltage, and power factor.

$$I = \frac{P}{E \times \text{p.f.}} \qquad E = \frac{P}{I \times \text{p.f.}} \qquad P = E \times I \times \text{p.f.} \qquad \text{p.f.} = \frac{P}{E \times I} \tag{49}$$

where I = current in amperes; P = power in watts; E = pressure in volts between lines; and p.f. = power factor.

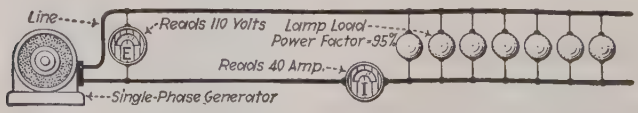


Fig. 44.—A power-factor problem.

Examples.—Figures 42 and 44 show examples of application of the above equations. The product of volts and amperes (EI) is called volt-amperes; see above paragraph.

Example.—In the circuit of Fig. 44, what is the actual load in watts? In kilowatts? Current = 40 amp., voltage at load = 110, power factor of load = 95 per cent.

Solution.—Substitute in the formula:

$$P = E \times I \times \text{p.f.} = 110 \times 40 \times 0.95 = 4{,}180 \text{ watts}$$

$$\text{Kw.} = \frac{\text{watts}}{1{,}000} = \frac{4{,}180}{1{,}000} = 4.18 \text{ kw.}$$

141. A two-phase current consists of two currents that differ in phase by 90 degrees (see curves of Fig. 45). If two sets of coils are arranged on

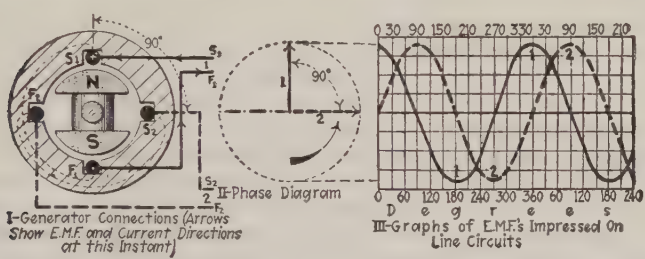


FIG. 45.—Two-pole two-phase a-c generator illustrating elementary principles.

an armature (Fig. 45) so that their "starts" S_1 and S_2 are 90 electrical degrees apart, then the e.m.f. in one set will attain its maximum value 90 degrees later than that in the other. The e.m.f. will force two-phase currents through an external circuit. Instead of being on the same armature, each of the sets of coils might be on different armatures which are so mechanically connected together as to preserve the 90 degree phase relation (see Croft, "Practical Electricity" and Div. **7** on Motors and Generators for information on practical machines).

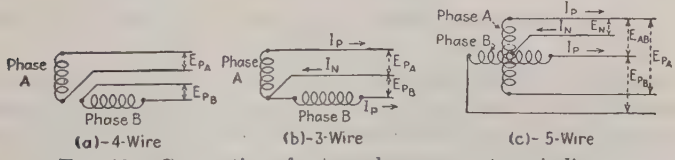


FIG. 46.—Connections for two-phase generator windings.

142. Coil Connections for Two Phase.—Figure 46 shows three methods of connecting two-phase generator coils.

143. Relations of Voltage, Current, and Power That Apply to Balanced Two-phase Circuits.—

$$I_p = \frac{P}{2E_p \times \text{p.f.}} \qquad E = \frac{P}{2I_p \times \text{p.f.}} \qquad P = 2E_p \times I_p \times \text{p.f.}$$

$$\text{P.f.} = \frac{P}{2E_p \times I_p} \quad (50)$$

$$\text{Kilovolt-amperes} = \frac{2E_p \times I_p}{1{,}000} \quad \text{or} \quad \text{Kva.} = \frac{\text{kw.}}{\text{p.f.}} \tag{51}$$

$$\text{Kw.} = \text{kva.} \times \text{p.f.} \tag{52}$$

$$\text{P.f.} = \frac{\text{kw.}}{\text{kva.}} \tag{53}$$

where I_p = current in amperes; E_p = phase voltage as designated in Fig. 46; P = power in watts and p.f. = power factor.

144. Application of the Two-phase System.—Several years ago certain engineers advocated two-phase generators and distributing systems in preference to three-phase. It was then believed by them that unbalanced load on the phases would have less adverse effect on the performance of the two-phase equipment. Experience has proved that the three-phase system is preferable to and more economical than the two-phase for both transmission and distribution. It is seldom that two-phase equipment is now purchased except for additions to existing two-phase installations. See Sec. **30** of Div. 3 for relative weights of copper for different systems.

145. A three-phase current consists of three alternating currents that differ in phase by 120 degrees, as indicated in Fig. 47. If three coils

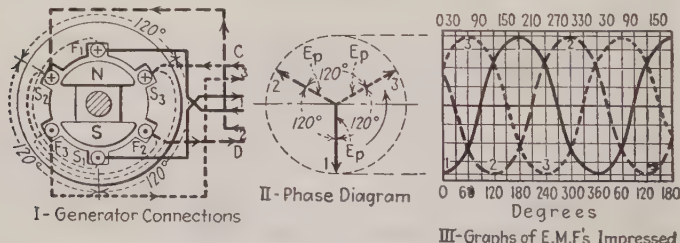


FIG. 47.—Two-pole three-phase alternator ensures 120 degrees phase difference between e.m.fs. in line wires.

are arranged with their "starts," S_1, S_2, and S_3, 120 degrees apart on an armature (Fig. 47) and connected each to an external circuit, a single-phase alternating e.m.f. will be impressed by each coil on its own external circuit when the field is rotated at uniform speed. The e.m.fs. will differ in phase by 120 degrees and therefore will constitute a three-phase system. The currents in the circuits will be 120 degrees out of phase with each other. Three single-phase generators, if mechanically coupled together so as to maintain a 120-degree phase relation, would produce a three-phase system. Practical three-phase generators usually have more than two poles and consequently have more coils than indicated in Fig. 47. Most alternating-current generators have revolving fields and stationary armatures.

146. Coil Connections.—Figure 48 shows four methods of connecting three-phase-generator (or other apparatus) coils and the external circuits

for each. Method I, although it would work, is seldom used for economic reasons hereinafter given. It shows the elementary three-phase circuit and illustrates the principle. Each of the three phases would carry a current differing in phase by 120 degrees from the currents in the other two. One common return N, as shown at II can be substituted for the

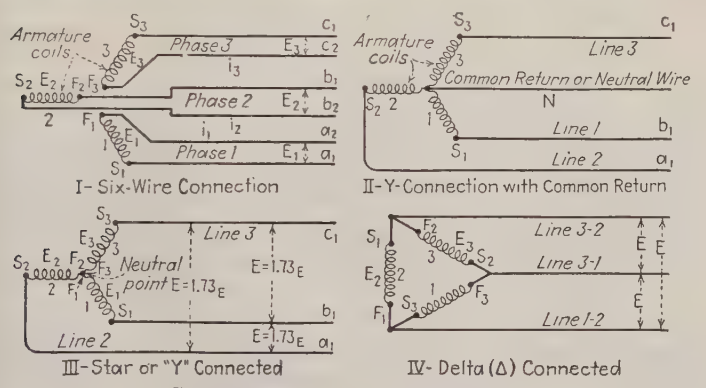


FIG. 48.—Connections for three-phase-generator windings.

three return wires of I. Now with a balanced load, *i.e.*, one loading each of the phases equally, this return wire would carry no current, hence it may be omitted (**star** or **Y connection** of III). In IV is shown the delta connection.

147. The voltage and current relations in a star or Y-connected three-phase circuit are indicated in Fig. 49. The armature coils of the gener-

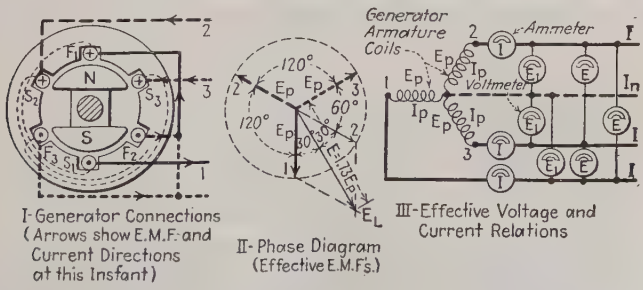


FIG. 49.—Star or Y-connected three-phase generator and diagrams.

ator shown in Fig. 49 are 120 electrical degrees apart (Fig. 47). These e.m.fs. will combine as shown in the phase diagram (Fig. 49) to produce the voltage E between line wires. The resultant voltage developed by any two of the coils is then equal to $\sqrt{3}$ or 1.73 times the voltage developed in one coil. The following formulas show the relation of voltage and

current in the circuit. (All are effective values and balance is assumed. See Fig. 49.)

$$I = I_p \tag{54}$$

$$E = E_p \times \sqrt{3} = E_p \times 1.73 \tag{55}$$

$$E_p = \frac{E}{\sqrt{3}} = \frac{E}{1.73} = E \times 0.577 \qquad \text{or approx. } E_p = 0.58E \tag{56}$$

$$I_N = 0 \tag{57}$$

where I = amperes per phase in the line; I_p = amperes per phase in each coil; E = volts between phase wires on the line; E_p = volts across each group of armature coils connected across each phase; and E_1 = volts between phase wires and neutral. The coils in Fig. 49, III, may represent the phase windings of a three-phase generator or transformer, or each coil may represent a transformer or other device, three of which are Y connected on a three-phase line.

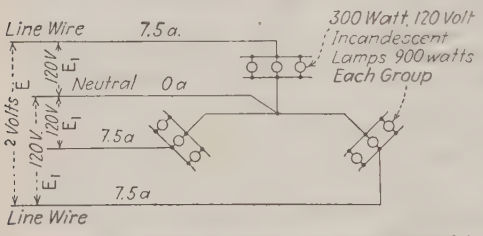


FIG. 50.—Incandescent lamp groups connected in star or Y.

Example.—What will be the voltage across line wires of the three-phase circuit for the 120-volt Y-connected lamps in Fig. 50?

Solution.—Substitute in the formula: $E = E_p \sqrt{3} = 120 \times 1.73 = 208$ volts.

148. Relations for a delta-(Δ) connected three-phase circuit are shown in Fig. 51. When armature-coils of a generator, see I, are connected as

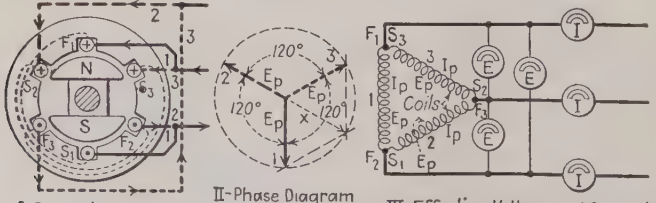


FIG. 51.—Delta (Δ)-connected three-phase generator and circuit.

indicated, the voltages generated in them are 120 degrees apart. It would appear that the current might flow around through the coils and not into the external circuit, but it is evident from the phase diagram II that the sum of the effective voltages 1 and 3 generated by two of the

coils is equal and opposite to that of the third. Hence, instead of tending to force current around internally, the voltages tend to force current out into the line. The following formulas indicate the relations of the voltages and currents. (All are effective values, and the circuit is assumed to be balanced. See Fig. 51.)

$$I = I_p \times \sqrt{3} = I_p \times 1.73 \tag{58}$$

$$I_p = \frac{I}{\sqrt{3}} = I \times 0.577 \qquad \text{or approx. } I_p = I \times 0.58 \tag{59}$$

$$E = E_p \tag{60}$$

where the symbols have the same meanings as in the preceding paragraph.

NOTE.—Each coil (Fig. 51) may represent the phase windings of a three-phase transformer or generator or each coil may represent a transformer or other device, three of which are Δ connected on a three-phase line.

Example.—If each of the coils of the generator in Fig. 51 can carry 100 amp., what value of current may be drawn from the line wires leading from the machine?

Solution.—Substitute in the formula:

$$I = I_p \times \sqrt{3} = 100 \times 1.73 = 173 \text{ amp.}$$

149. Relations of voltage, current, and power that apply to any balanced three-wire three-phase circuit either delta or Y connected.—

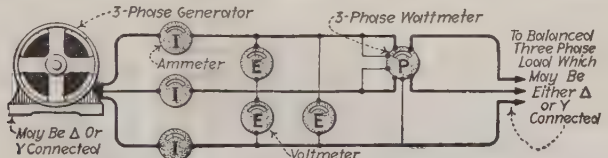


FIG. 52.—Relations for any (Δ- or Y-connected) three-phase circuit.

Refer to Fig. 52 for a key to the letters that appear in the following formulas. For a unity power factor load

$$I = \frac{P}{E \times \sqrt{3}} = \frac{0.577 \times P}{E} \qquad \text{or approx. } = \frac{0.58 \times P}{E} \tag{61}$$

$$E = \frac{P}{I \times \sqrt{3}} = \frac{0.577 \times P}{I} \qquad \text{or approx. } = \frac{0.58 \times P}{I} \tag{62}$$

$$P = E \times I \times \sqrt{3} = 1.73 \times E \times I \tag{63}$$

For any load

$$\text{P.f.} = \frac{P}{1.73 \times I \times E} = \frac{0.577 \times P}{I \times E} \qquad \text{or approx. } = \frac{0.58 \times P}{I \times E} \tag{64}$$

$$E = \frac{P}{\text{p.f.} \times 1.73 \times I} = \frac{0.577 \times P}{\text{p.f.} \times I} \qquad \text{or approx. } = \frac{0.58 \times P}{\text{p.f.} \times I} \tag{65}$$

$$I = \frac{P}{\text{p.f.} \times 1.73 \times E} = \frac{0.577 \times P}{\text{p.f.} \times E} \qquad \text{or approx. } = \frac{0.58 \times P}{\text{p.f.} \times E} \tag{66}$$

$$P = 1.73 \times E \times I \times \text{p.f.} \tag{67}$$

$$V.A. = 1.73 \times E \times I \tag{68}$$

where I = line current, in each of the three wires, in amperes; P = the power transmitted by all three wires in watts; E = voltage across lines; p.f. = the power factor of the circuit.

Example.—What is the power factor in the 220-volt circuit to the motor in Fig. 53? The three ammeters each indicate 90 amp., and the three-phase wattmeter indicates 30 kw. (30,000 watts).

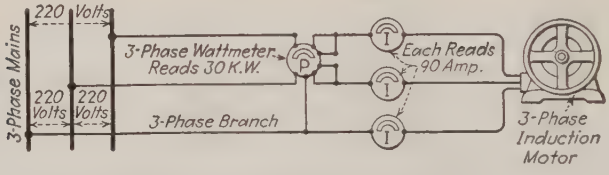


FIG. 53.—Motor on a three-phase circuit.

Solution.—Substitute in the formula:

$$\text{P.f.} = \frac{0.577 \times P}{I \times E} = 0.577 \times \frac{30{,}000}{90 \times 220} = \frac{17{,}310}{19{,}800} = 0.88 = 88 \text{ per cent power factor}$$

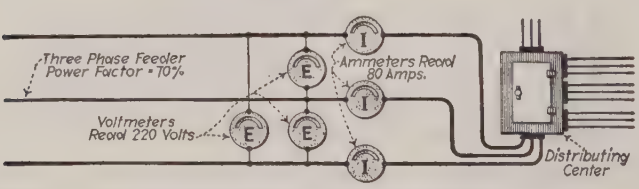


FIG. 54.—Load on a three-phase circuit.

Example.—The power factor on the feeder of Fig. 54 is known to be 70 per cent. The current in each line is 80 amp., and the voltage across each phase is 220. What actual power is being delivered to the panel box?

Solution.—Substitute in the formula:

$$P = 1.73 \times E \times I \times \text{p.f.} = 1.73 \times 220 \times 80 \times 0.70 = 21{,}313.6 \text{ watts}$$

$$\text{Kw.} = \frac{\text{watts}}{1{,}000} = \frac{21{,}313.6}{1{,}000} = 21.3 \text{ kw.}$$

Examples.—Figure 55 shows some numerical examples of voltage and current relations in a three-phase circuit. Note that when a group of three devices or coils is connected in delta, as in the motor, each device or coil has line voltage impressed on it and must be designed for that voltage. The current in the line will be 1.73 times the current through the coil. When Y connected, as on the low-voltage side of the transformers, each of the three coils need only be designed for 1/1.73 or 0.577 times the line voltage, and the line current will be the same as the current through each coil. Single-phase loads may be supplied either from line to neutral as with the 120-volt lamps or from two lines as with the 208-volt heater.

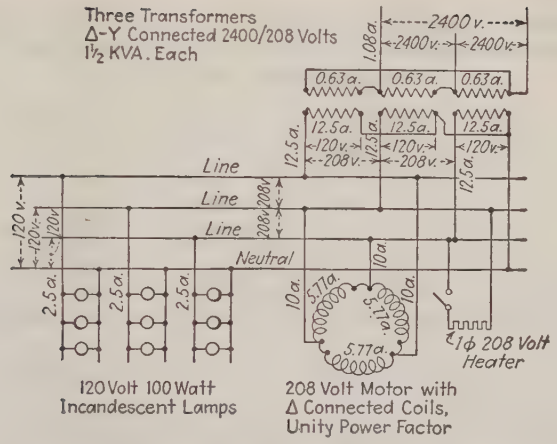


FIG. 55.—Examples of current and voltage relations in three-phase circuits.

150. The power loss in any circuit traversed by an alternating or a direct current is

$$P = I^2 \times R \qquad \text{or} \qquad I = \sqrt{\frac{P}{R}} \qquad \text{or} \qquad R = \frac{P}{I^2} \tag{69}$$

where P = the **power** lost in heat in the circuit in watts; I = effective current in amperes in the conductor; and R = resistance of conductor

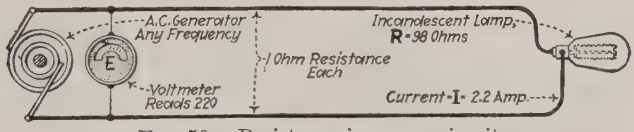


FIG. 56.—Resistance in an a-c circuit.

in ohms. This rule is perfectly general and applies to all d-c circuits and all a-c circuits of ordinary voltages and frequencies. The watts **power** loss P reappears as heat **power** and heats the conductors.

Example.—What is the **power** loss in the incandescent lamp in Fig. 56?
Solution.—Substitute in the formula:

$$P = I^2 \times R = (2.2 \times 2.2)98 = 4.84 \times 98 = 474 \text{ watts}$$

Example.—What is the **power** loss in the inductive winding of Fig. 57 with an alternating current of 3 amp?
Solution.—Substitute in the formula:

$$P = I^2 \times R = (3 \times 3)7 = 9 \times 7 = 63 \text{ watts}$$

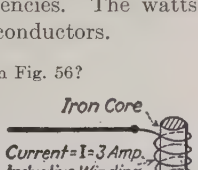


FIG. 57.—Effective resistance in an inductive a-c circuit.

NOTE.—In the circuit of Fig. 57 the resistance of the coil to direct current is only 5 ohms. The increase in resistance to alternating current over its d-c value is due to the power losses produced in the iron core (refer to Sec. **112**).

151. Approximate Sparking Distances, in Air, for Various Mean Effective Voltages between Sharp Needle Points. Sine-wave-form Voltage
(Locke Insulator Company)

Voltage	Distance		Voltage	Distance	
	In.	Cm.		In.	Cm.
1,000	0.06	0.152	20,000	1.00	2.54
2,000	0.13	0.33	25,000	1.30	3.3
3,000	0.16	0.41	30,000	1.63	4.1
4,000	0.22	0.56	35,000	2.00	5.1
5,000	0.23	0.57	40,000	2.45	6.2
10,000	0.47	1.19	50,000	3.55	9.0
15,000	0.73	1.84	100,000	9.60	24.4

NOTE.—Above 100,000 volts, the gap between needle points is approximately 1 in. per 10,000 volts. Using infinitely sharp needle points up to at least 10,000 volts, a graph of the voltage and the corresponding sparking distance would probably result in a straight line passing through the origin. (H. W. Fisher, *Trans. Int. Elect. Cong.*, 1904, Vol. II, p. 294.)

152. Dielectric Strength.—When there is an e.m.f. between two conductors that are separated by an insulating material, there are electrical forces exerted upon the electrons in the atoms of the insulating material. These electric forces are trying to pull the electrons out of the atoms. If these forces succeed in pulling the electrons out of the atoms, the material ceases to be an insulator and becomes a conductor. When this occurs, it would be said that the insulation had broken down. When the voltage between the conductors is small, the forces exerted in the atoms are not great enough to pull the electrons out of the atoms. As the voltage between the conductors is increased, the forces on the electrons are increased. If the voltage continues to be increased, the forces will eventually become great enough to pull the electrons out of the atoms, and the insulation will break down. The voltage at which the material ceases to be an insulator is called the breakdown voltage. Any insulating material can be broken down and cease to be an insulator if the voltage impressed across it is raised high enough. The breakdown voltage of any material depends upon the thickness, condition of the surface, and homogeneity of the material. The breakdown voltage does not increase directly with the thickness of the material; a piece of material 2 in. thick will break down at a voltage less than twice the breakdown voltage of a piece 1 in. thick. Any irregularities or sharp points on the surface will lower the breakdown voltage.

It is the above considerations that govern the thickness of insulation required on conductors, the spacing of bare conductors, distance between live parts and ground, etc.

153. Bus-bar Spacings, Minimum Distance between Parts of Opposite Polarity and Minimum Distance between Live Parts and Ground for Different Voltages

(Electrical Engineer's Equipment Co.)

Voltage	Distance between centers of buses, in.		Minimum distance between opposite live parts, in.		Minimum distance between live parts and ground, in.	
	A	*B*	*A*	*B*	*A*	*B*
250	1½	2½	1	2	¾	1½
600	2	3	1½	2½	1	2
1,100	4	5	2½	3½	1½	2½
2,300	5	6½	2¾	4	2	2¾
4,000	6	7½	3	4½	2¼	3
6,600	7	8	3½	4½	2½	3
7,500	8	9	4	4½	2¾	3¼
9,000	9	10	4¼	4½	3	3½
11,000	9	11	4½	4¾	3¼	3¾
13,200	9	12	4¾	5	3½	4¼
15,000	9	14	5	5½	3¾	4½
16,500	10	14	5½	6	4½	5
18,000	11	14	6	7	5	6
22,000	12	15	7½	9	6	7
26,000	14	16	10	12	8	9
35,000	18	22	12	15	10	12
45,000	22	27	16	18	13½	15
56,000	28	31	17½	19	16	17½
66,000	34	38	22	24	18½	23
75,000	36	42	26	30	25	27½
90,000	46	54	32	35	27	29
104,000	54	60	34½	39	28½	32
110,000	60	72	38	41	33	36
122,000	66	78	42	47	35½	39
134,000	74	84	48½	56	39	41
148,000	82	96	59	67	45	50
160,000	88	104	70	84	53	62

NOTE.—The distances given in the *A* columns are based on a safety factor of 3.5 between live parts of opposite polarity and safety factor of 3 between live parts and ground. *B* column shows good practice for the larger plants. Tubular busses should be used on all busses above 22,000 volts. Bus support porcelains should have a wet test of two times voltage used.

MEASURING, TESTING, AND INSTRUMENTS

154. Electricians often test circuits for the presence of voltage by touching the conductors with the fingers. This method is safe where the voltage does not exceed 250 and is often very convenient for locating a blown-out fuse or for ascertaining whether or not a circuit is alive. Some men can endure the electric shock that results without discomfort whereas others cannot. Therefore, the method is not feasible in some cases. Which are the outside wires and which is the neutral wire of a 115/230-volt, three-wire system can be determined in this way by noting

the intensity of the shock that results by touching different pairs of wires with fingers. Use the method with caution and be certain that the voltage of the circuit does not exceed 250 before touching the conductors. (This and the several paragraphs that follow are taken from *Electrical Engineering.*)

155. The presence of low voltages can be determined by tasting. The method is feasible only where the pressure is but a few volts and hence is used only in bell and signal work. Where the voltage is very low, the bared ends of the conductors constituting the two sides of the circuit are held a short distance apart on the tongue. If voltage is present a peculiar mildly burning sensation results, which will never be forgotten after one has experienced it. The taste is due to the electrolytic decomposition of the liquids on the tongue which produces a salt having a taste. With voltages of 4 or 5 volts, due to as many cells of a battery, it is best to test for the presence of voltage by holding one of the bared conductors in the hand and touching the other to the tongue. Where a terminal of the battery is grounded, often a taste can be detected by standing on moist ground and touching a conductor from the other battery terminal to the tongue. Care should be exercised to prevent the two conductor ends from touching each other at the tongue, for if they do a spark can result that may burn.

156. The magneto test set is one of the most valuable testing instruments to the practical man because of its simplicity and the fact that it is

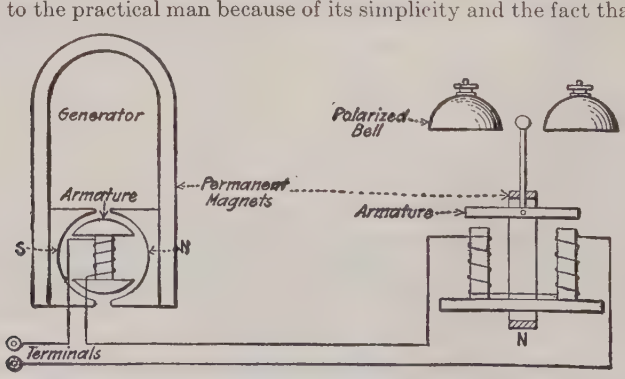


FIG. 58.—Circuits of testing magneto.

always ready for service. Figure 58 shows the circuit and Fig. 59 a perspective view of a testing magneto. The apparatus consists of a small hand-operated a-c generator in series with a polarized electric bell. Alternating current will ring bells of this type. If the external circuit connected to the terminals of the magneto is closed and the crank of the generator is turned, current will flow and the bell will ring.

The resistance through which magnetos will ring is determined by

their design. An ordinary magneto will ring through possibly 20,000 to 40,000 ohms. Electrostatic capacity effects must be considered when testing with a magneto. When testing long circuits, such as telephone lines or circuits that are carried in cable for a considerable distance, the bell of the magneto may ring, owing to capacity, apparently indicating a short circuit, whereas the circuit may be perfectly clear or open. Circuits associated with iron, such as field coils of generators, may have considerable inductance. With highly inductive circuits under test, the magneto may "ring open," *i.e.*, the bell may not ring at all, even though the inductive circuit connected to it be actually closed. In ordinary interior-wiring work the effects of capacity and inductance are usually negligible, and the true condition of the circuit will be indicated by the performance of the magneto bell.

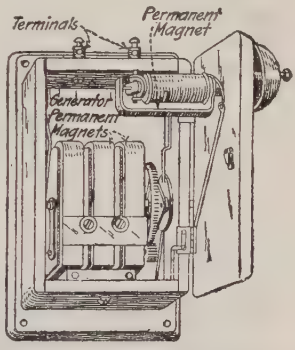


FIG. 59.—Assembly of testing magneto.

157. A telephone receiver in combination with one or two dry cells constitutes an excellent equipment for certain tests. A "head"-telephone receiver (Fig. 60) is usually preferable to those of the watchcase types, because it is held on the head by the metal strap, allowing the unrestricted use of both hands. Metal testing clips are soldered to the flexible testing cords. The telephone receiver is extremely sensitive and will give a weak "click" even when the current to it passes through an exceedingly high resistance. In using, one clip is gripped on one conductor of the circuit to be tested and the other clip is tapped against the other conductor. Prolonged connection should be avoided because it will "run down" the battery. A vigorous click of the receiver indicates a closed circuit, while a weak click or none at all indicates an open circuit. After practice it is possible to determine approximately the resistance of the circuit under test by the intensity of the receiver click. When the battery and receiver test set are connected to a circuit having some electrostatic capacity, the receiver will give a vigorous click when the clips are first touched to the circuit terminals, even though the circuit be open. With successive touchings the click will diminish in intensity if the circuit is open but will not diminish appreciably if the circuit is closed.

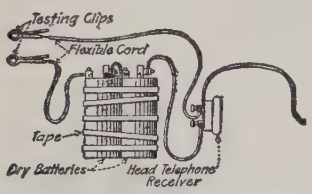


FIG. 60.—Head-telephone and dry-battery testing set.

158. The advantages of the telephone receiver over the magneto for work of certain classes are (1) The receiver and battery outfit costs little. (2) The outfit can be made so compact that it can be carried in the pocket. (3) In making insulation tests with a magneto the circuit may "ring clear," *i.e.*, the bell will not ring, apparently indicating high insulation resistance, whereas the circuit may not be clear, but instead the magneto may be out of order or its local circuit open. The indication is negative. With the telephone receiver a slight click is produced even when testing through the highest resistances. The absence of a click usually signifies an open in the testing apparatus itself. Thus the telephone receiver indication is positive.

159. A telegraph sounder is sometimes used for testing. It is connected in the same way as the telephone receiver of Fig. 60 and is adaptable for rough work. When the circuit under test is closed and the flexible-cord clips are touched to the circuit conductors, the sounder clicks. Where the circuit is open there is no click. One feature of the sounder method is that the click is audible at a considerable distance from the instrument.

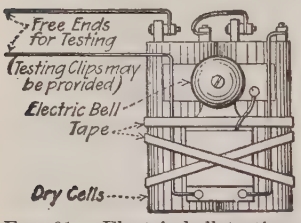


FIG. 61.—Electric-bell testing outfit.

160. An electric-bell outfit for testing is shown in Fig. 61. When the free ends for testing are touched to a closed circuit of not too high resistance the bell rings. Where the circuit is open the bell will not ring. Flexible cord can be used for the testing conductors of the outfit, and testing clips can be provided as in Fig. 60.

161. A test lamp (Fig. 62), consisting merely of a weatherproof rubber-insulated socket into which is screwed an incandescent lamp of the highest voltage rating of the circuits involved, is very convenient for rough tests on interior-lighting and motor-wiring systems. Porcelain sockets are undesirable because they are so readily broken. Brass sockets should not be used because they may fall across conductors and thereby cause short circuits. Testing clips may be soldered to the ends of the leads which are molded in the socket. Some uses of the testing lamp are given in a following paragraph, and it is very convenient for testing for defective fuses.

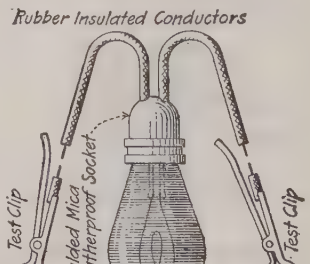
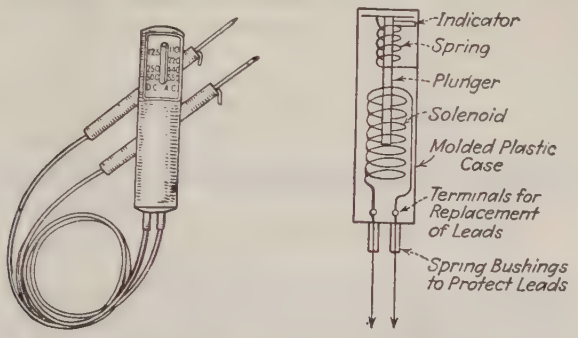


FIG. 62.—A practical test-lamp outfit.

162. A very convenient and inexpensive test outfit consists of a pointer which moves along a scale inside an insulated case (Fig. 63). It indicates



I. Assembly. II. Schematic diagram.

FIG. 63.—Voltage tester, 110 to 600 volts. (*Square D Co.*)

whether the circuit is alternating or direct current by vibrating on alternating current, the frequency of vibrations showing whether it is 25 or 60 cycles. It indicates the range of voltage of the circuit up to 550 a.c. or 600 d.c. The sharp points on the end of the lead wires can be used to pierce insulation for checking insulated leads without destroying the insulation.

163. Neon-glow lamp testers provide a very convenient and compact device for determining if a circuit is live, for determining polarity of d-c circuits, and for determining if a circuit is alternating or direct current. A neon tester for low-voltage work is illustrated in Fig. 64. It consists of a very small neon lamp in series with a 200,000-ohm protective resistance enclosed in a molded case. This tester is satisfactory for use on circuits of from 90 volts d.c. or 60 volts a.c. to 500 volts a.c. or d.c. With the test tips connected to a circuit, the presence of voltage within the above limits will be indicated by the glowing of the neon lamp. If both electrodes in the bulb glow the voltage of the circuit is alternating. On direct current, only one electrode, the one connected to the negative side of the circuit, will glow. With experience the voltage of the line can be approximately determined by the intensity of the glow. In testing a circuit it is best first to touch only one side of the line with

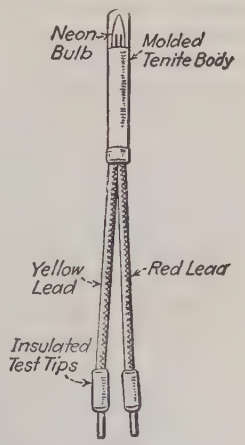


FIG. 64.—Neon glow-lamp tester. (*Littlefuse, Inc.*)

one test tip, keeping the other test tip free. A glow with this connection will indicate the presence of high voltage. The tester indicated is well constructed for safety. The molded case has a voltage breakdown value of 25,000 volts, and the leads are insulated for 5,000 volts and provided with insulated test prods.

Glow-tube testers are available for testing for the presence of voltage on high-voltage circuits. In testing high-voltage circuits by this means,

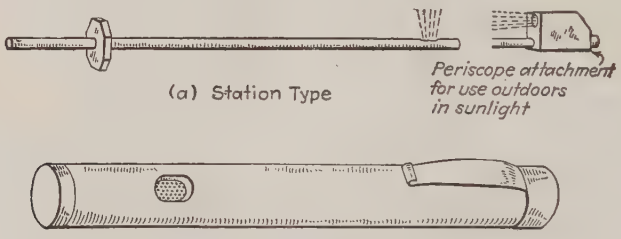


FIG. 65.—Statiscopes. (*Minerallac Electric Co.*)

no direct connection is made to the circuit. The end of the tester which contains the glow tube is simply held in proximity to the circuit. The changing electrostatic field will ionize the gas inside the tube and cause it to glow. These testers or statiscopes as they are called will indicate the presence of potential in a-c circuits, pulsating d-c circuits, X-ray equipment circuits, static from belting, high-frequency circuits, condenser discharges, and automobile ignition. On a-c circuits they will give positive indication on 2,000 volts and up. Materials which will act as shields to the electrostatic field, such as lead on underground conductors, metal cabinets, and grounded framework, must not be between the tester and the conductors of the circuit being tested. A pocket type of statiscope is shown in Fig. 65*b*. They are also made in types especially adapted for the testing of overhead lines and station equipment (Fig. 65*a*).

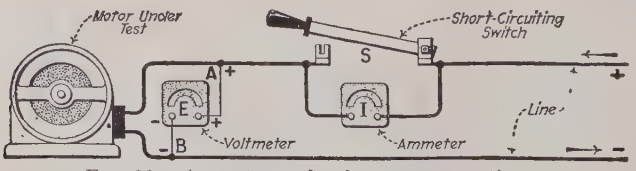


FIG. 66.—Ammeter and voltmeter connections.

164. Rules for Use of Ammeter and Voltmeter (Timbie, "Elements of Electricity").—Place ammeter in series, always using a short-circuiting switch, where possible, as shown in Fig. 66, to prevent injury to the instrument. Place voltmeter in shunt (Fig. 66). Put the + side of the instrument on the + side of the line. Figure 66 shows the correct use of an

ammeter and a voltmeter to measure the current and the voltage supplied to the motor. The short-circuiting switch S must be opened before the ammeter is read. All the current that enters the motor must then flow through the ammeter and be indicated. The ammeter is of very low resistance (about 0.001 or 0.002 ohm) and does not appreciably cut down the flow of current. The voltmeter is of very high resistance (about 15,000 ohms) and does not allow any appreciable current to flow through itself. Yet enough goes through the voltmeter to cause it to indicate the voltage across the terminal AB of the motor. Suppose the voltage across the motor to be 110, what would happen if an ammeter of 0.002-ohm resistance were by mistake placed across AB? (Remember Ohm's law is always in operation.)

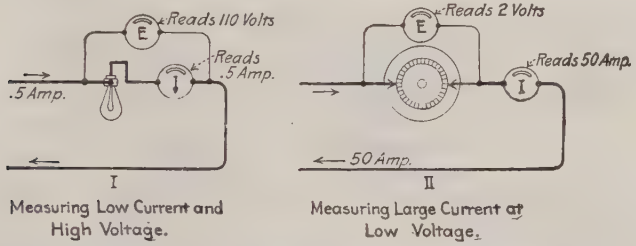


FIG. 67.—Correct methods of connecting instruments.

165. All ammeters and voltmeters (except electrostatic) consume power when in use and introduce some error (Timbie, "Elements of Electricity"). For minimum error (see Fig. 67, I) when measuring a low current and high voltage, the voltmeter should be placed around both the ammeter and the apparatus under test.

When measuring the power consumed by a piece of apparatus, through which a large current at low voltage is flowing, the voltmeter should be placed immediately across the piece of apparatus under test and not across the ammeter (Fig. 67, II).

166. Ohm's law is often applied in making determinations of resistance, voltage, current, and power. In Secs. **67** and **68** examples are given that indicate the application of Ohm's law to measurements.

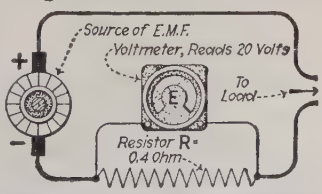


FIG. 68.—Current measurement with voltmeter.

167. A method of measuring current with a voltmeter is shown in Fig. 68. If a resistor of known resistance is connected in series in a circuit and the voltage across the resistor measured with a voltmeter, the current can be determined by Ohm's law, thus:

Example (Fig. 68).—If the drop around a 0.4-ohm resistance in series in a circuit is 20 volts, what is the current in the circuit?

Solution.—Substitute in the Ohm's law formula:

$$I = \frac{E}{R} = \frac{20}{0.4} = 50 \text{ amp.}$$

168. A millivoltmeter is generally used for making measurements like that of Sec. **167.** A millivoltmeter reads in thousandths of volts so that a resistor of small resistance can be used. Ammeters, particularly those for large currents, are often millivoltmeters calibrated in amperes which are connected around a resistor, in series with the circuit (Fig. 69). The resistor is sometimes in the instrument case and is sometimes inserted in the bus bars of a switchboard (see Fig. 69). Such resistors are called **shunts** and when furnished by instrument makers are carefully calibrated.

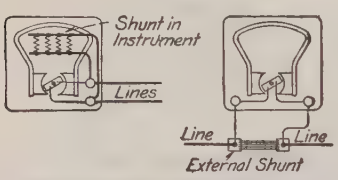


FIG. 69.—Millivoltmeters and shunts.

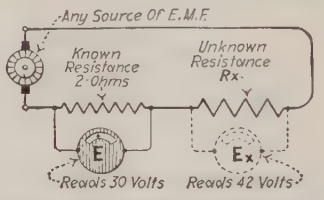


FIG. 70.—Resistance measurement.

169. Resistances can be measured with a voltmeter as indicated in Fig. 70. This method is satisfactory for the measurement of resistances whose values range from a few to a few hundred ohms. A resistor of known resistance, a source of direct current, and one voltmeter are required. The same constant current flows through both the known and the unknown resistance. The voltmeter reading E is taken and then the reading E_x. The voltage drops will be proportional to the resistances or

$$\frac{R}{E} = \frac{R_x}{E_x} \quad \text{or} \quad R_x = \frac{E_x \times R}{E} \tag{70}$$

Example.—Substituting the values from Fig. 70 in the formula,

$$R_x = \frac{E_x \times R}{E} = \frac{42 \times 2}{30} = \frac{84}{30} = 2.8 \text{ ohms}$$

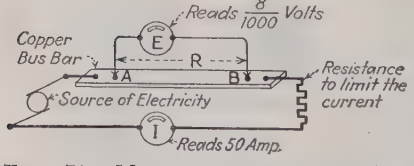


FIG. 71.—Measurement of very low resistance.

170. Very small resistances can be measured, as indicated in Fig. 71, with an ammeter and with a voltmeter. This method is generally satisfactory for resistances having a value of less than 1 ohm and is convenient for measuring the resistance of bus bars, joints between conductors, switch contacts, brush-contact resistance, and

other low resistances. As large a current as is feasible should be used. This is another application of Ohm's law.

Example.—What is the resistance of the portion of the bus bar between A and B, Fig. 71?

Solution.—Substitute in Ohm's law formula:

$$R = \frac{E}{I} = \frac{0.008}{50} = 0.00016 \text{ ohm}$$

In the application of Ohm's law as given here, the current through the voltmeter is neglected. Since the resistance of the voltmeter is generally large compared with the resistance to be measured, the error involved by neglecting the voltmeter current is generally negligible.

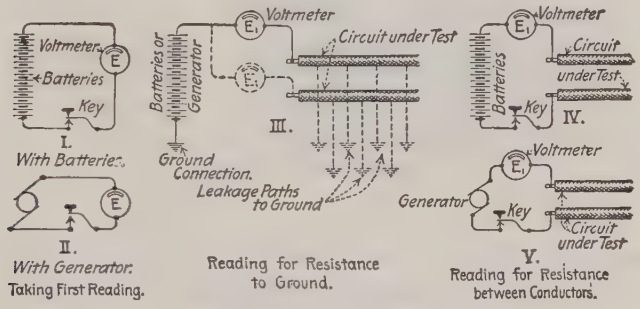


FIG. 72.—Measuring insulation resistance.

171. Insulation resistance is frequently measured as suggested in Fig. 72. A voltmeter of known resistance, preferably of high resistance, and a source of e.m.f. (batteries or a generator) are required. First the voltage of the e.m.f. source is taken as shown at I or II. The apparatus is then arranged as shown at III to measure the resistance from each side of the circuit to ground. At IV or V are shown the connections for measuring the resistance between conductors. If E = voltage of source; E_1 = reading of voltmeter when connected in series with insulation resistance to be measured; R_v = resistance, in ohms, of voltmeter; and R_x = insulation resistance sought, the following formula is used (see Fig. 72):

$$R_x = R_v \left(\frac{E}{E_1} - 1 \right) \tag{71}$$

Example.—In a certain test (Fig. 73) where a 110-volt generator was used as a source of e.m.f. and a voltmeter having a resistance of 15,000 ohms was used to read voltages, the readings indicated in Fig. 73 were obtained. What was the insulation resistance to ground of each side of the circuit and what was the insulation resistance between circuits?

Solution.—For the resistance of conductor 1 (see Fig. 73) substitute in the formula:

$$R_x = R_v\left(\frac{E}{E_1} - 1\right) = 15{,}000\left(\frac{110}{5} - 1\right) = 15{,}000(22 - 1) = 15{,}000 \times 21$$

= 315,000 ohms = insulation resistance of conductor 1 to ground

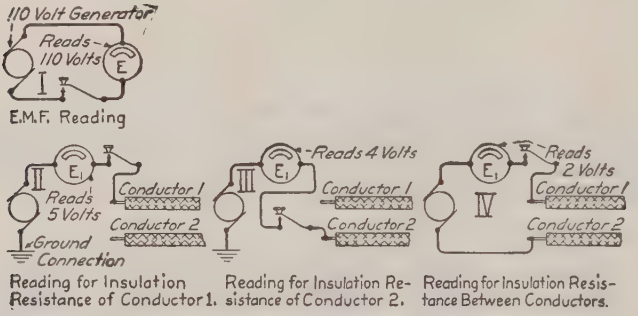


FIG. 73.—Example of insulation-resistance measurement.

For the resistance of conductor 2 (see Fig. 73, III):

$$R_x = R_v\left(\frac{E}{E_1} - 1\right) = 15{,}000\left(\frac{110}{4} - 1\right) = 15{,}000(27.5 - 1) = 15{,}000 \times 26.5$$

= 397,500 ohms = insulation resistance of conductor 2 to ground

For the insulation resistance between conductors:

$$R_x = R_v\left(\frac{E}{E_1} - 1\right) = 15{,}000\left(\frac{110}{2} - 1\right) = 15{,}000(55 - 1) = 15{,}000 \times 54$$

= 810,000 ohms = insulation resistance between conductors 1 and 2.

172. The insulation resistance of a generator can be determined with a voltmeter of known resistance which is successively connected and read

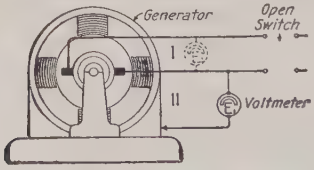


FIG. 74.—Measuring insulation resistance of a generator.

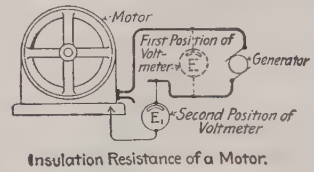


FIG. 75.—Measuring insulation resistance of a motor.

in positions I and II (Fig. 74). The formula of Sec. **171** is used. The external circuit connected to the generator should be cut off while the measurements are being taken, so that its insulation resistance will not affect the readings.

173. The insulation resistance of a motor can be measured with a voltmeter as suggested in Fig. 75. The formula of Sec. **171** is used. Unless the external circuit has high insulation resistance, its resistance will affect the result.

174. The ohmmeter (Fig. 76) is an instrument to measure resistance where accuracy of about $\frac{1}{4}$ of 1 per cent is satisfactory. It consists of a sensitive galvanometer and a number of resistances which can be successively connected into the circuit with a selector switch in order to obtain several scale ranges. From one to four dry cells, the number depending on the resistance range to be used, are connected in series across one pair of terminals. The resistance to be measured is connected across another pair of terminals. There is an adjusting rheostat to compensate for changes in battery voltage, and the zero reading must be checked and adjusted before taking a resistance reading. The scale is calibrated directly in ohms.

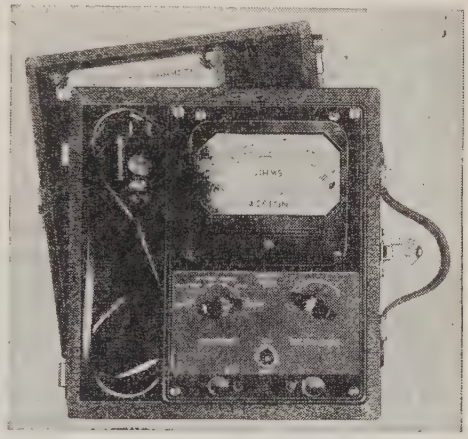


FIG. 76.—Ohmmeter. (*Weston Electrical Instrument Corp.*)

175. A megger (Fig. 77) is an instrument frequently used to measure high resistance. It consists of a magneto which is turned by a crank on

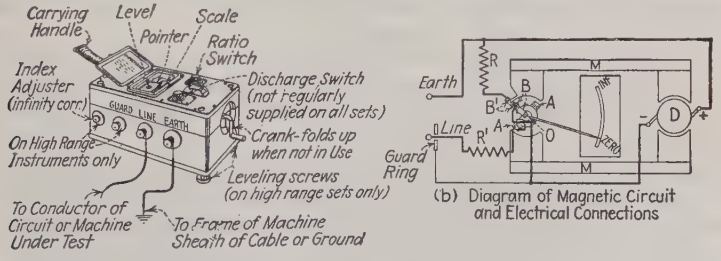


FIG. 77.—Megger. (*James G. Biddle Co.*)

the side of the case. The scale is calibrated directly in ohms. The resistance to be measured is connected across two terminals. The crank is turned at a moderate speed (about 120 r.p.m.) until the pointer reaches a steady deflection.

176. Power, in d-c or unity-power-factor single-phase a-c electric circuits, can be measured with a voltmeter and an ammeter. For two-

wire circuits the power in watts, in accordance with Ohm's law, equals the product of volts times amperes, thus

$$P = I \times E \tag{72}$$

where P = the power in watts; I = the current in amperes; and E = the e.m.f. in volts.

Example.—See Sec. **91** for examples of power problems. Although no instruments are shown in these, the principles are the same as if instruments were used.

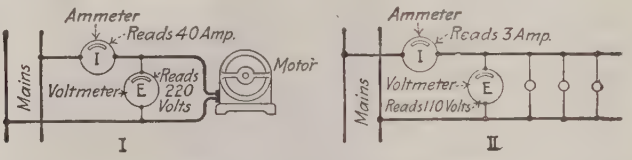


Fig. 78.—Power measurements.

Example.—In Fig. 78, I, the power taken by the motor is, substituting in the formula,

$$P = I \times E = 40 \times 220 = 8{,}800 \text{ watts}$$

or in kilowatts = 8,800/1,000 = 8.8 kw.

Example.—In Fig. 78, II, the power taken by the lamps is

$$P = I \times E = 3 \times 110 = 330 \text{ watts}$$

or in kilowatts 330/1,000 = 0.33 kw.

177. Power in single-phase a-c circuits must be measured with a wattmeter unless the power factor is unity. A wattmeter may also be employed for measuring the power of a d-c circuit. A wattmeter has two internal coils, namely, a voltage coil and a current coil. The voltage coil is connected across the circuit in which the power is to be measured, and the current coil is connected in series with the circuit. The wattmeter gives a direct indication of the power of the circuit. Two methods of connecting a wattmeter for measuring the power of a d-c or of a single-phase a-c circuit are shown in Figs. 41 and 42. In Fig. 41 the voltage coil is connected between the generator and the current coil of the wattmeter, while in Fig. 42 the voltage coil is connected between the load and the current coil of the wattmeter. The connection of Fig. 41 should be used for loads of small current and that of Fig. 42 for loads of large current.

178. Power in a two-phase system can be measured with two single-phase wattmeters connected as shown in Fig. 79. Each phase is treated as a separate circuit. One wattmeter reads the power of one phase, and the other the power of the second phase. The total power is the arithmetical sum of the two wattmeter readings, *i.e.*,

$$\text{Total power} = P_1 + P_2 \tag{73}$$

A polyphase wattmeter, connected as shown in Fig. 79, III, can be used for the measurement of the power of a two-phase system.

179. Power in three-phase circuits can be measured with wattmeters by several different methods (see Fig. 80). At I a polyphase wattmeter is shown. An instrument of this type automatically adds the portions of power consumed in each phase and indicates their sum. Instruments made by different manufacturers are arranged differently and must be connected accordingly. Directions accompany each instrument. Diagrams II and III show how the power can be measured, in a balanced circuit, with one wattmeter. One potential lead is connected to the line in which the wattmeter is inserted, and the other potential lead is connected successively to the other two lines. The total power in II is equal to the sum or differ-

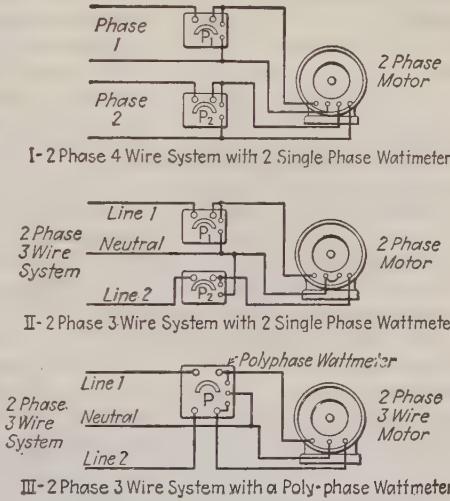


FIG. 79.—Measurement of power in two-phase systems.

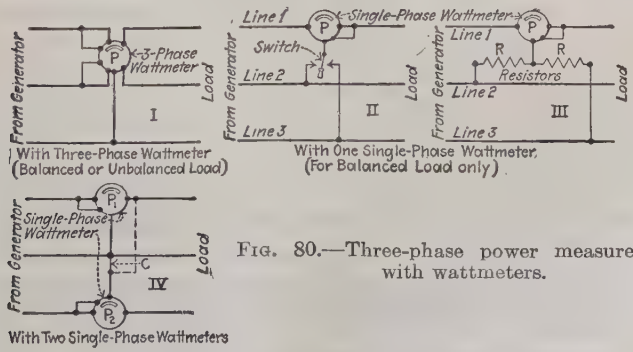


FIG. 80.—Three-phase power measurements with wattmeters.

ence of the two readings. If resistors are used as indicated in III, the power can be ascertained without any shifting of leads. The wattmeter reading of III multiplied by 3 will be the true power in a balanced

circuit. The resistance of each of the resistors R and R must be equal to the resistance of the potential or voltage coil of the wattmeter.

With two wattmeters (as in Fig. 80, IV) the total power is equal to the (sum or difference) of the two wattmeter readings. If the power factor is greater than 0.50 the total power is the arithmetical sum of the readings. If it is lower than 0.50, one of the readings is negative and the power is their arithmetical difference. To ascertain whether one of the wattmeters is reading negative, temporarily transfer the connection of one of the potential wires (for example *c* in IV, as shown by the dotted line) from the middle wire to the outside wire. If its wattmeter reverses, one of the instruments, that of the lesser indication, is reading negatively. The nature of the load usually enables one to judge roughly what the power factor is. With incandescent lamps and fully loaded motors the power factor will be high, but with under and lightly loaded motors it is likely to be low. See Sec. **181** for method of determining the **power factor** of three-phase circuits **with wattmeters.**

180. The power factor of a circuit can be determined from readings of voltmeters, ammeters, and wattmeters by use of the formulas of Secs. **139, 143,** and **149.** The power factors of circuits can also be determined by instruments called power-factor meters, which when properly connected in a circuit read the power factor directly.

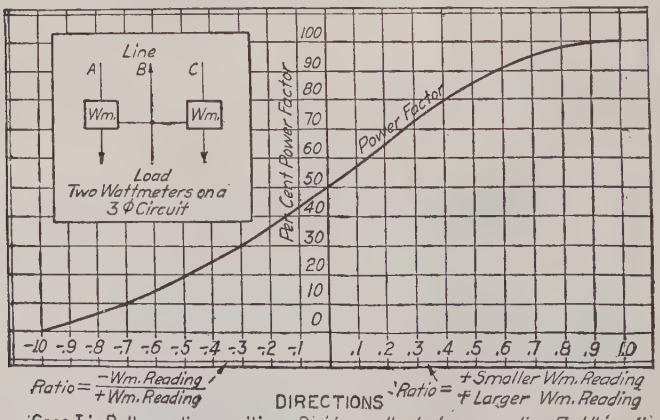
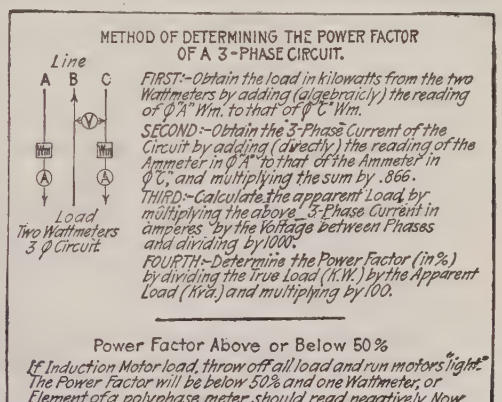


FIG. 81.—Power-factor curve.

181. The method of determining three-phase power factor with watt-meters was well described by C. E. Howell in *Electrical World*. It is necessary to know the power factor in order to connect watt-hour meters correctly where the wiring is concealed. An abstract follows:

Figure 81 shows the power-factor curve for two single-phase meters on a polyphase circuit. It also gives a diagram of connections and instructions as to how to use the curve. The figure should be self-explanatory. Figure 82 gives, first, a method of checking results obtained by employing the curve given in Fig. 81 and a diagram of the connections for obtaining data for the check. The second part of Fig. 82 gives a method of determining the correct connections for two single-phase meters, or one polyphase meter, on a three-phase circuit. If this part of Fig. 82 is followed, errors in meter connections on three-phase circuits due to the power factor being near 50 per cent should be minimum.



Note.—This is based on the fact that on "no load" the power factor of an induction motor is below 50 per cent.

FIG. 82.—Chart of instructions for power-factor test.

To illustrate the use of the above instructions: A 100-hp. three-phase 440-volt induction motor was operating on 30 per cent full load or 30 hp. (29.8 kw.) at 60 per cent power factor (afterward determined) when an order "came through" to place a polyphase watt-hour meter on the installation. Immediately after the meter had been connected the following question was asked: "Should the light element add to or subtract from the heavy element; *i.e.*, is the power factor above or below 50 per cent?" As the meter leads were encased in pipe, they could not be traced, therefore the instructions in the second figure pertaining to this point were applied. The connected load of the motor having been thrown off, it was found that one element of the meter gave a negative reading. Sufficient load was then put on to bring the motor to about 80 per cent of its full-load rating. Each element of the meter (taken separately) now read positively, but the element which on no load gave a negative reading

on 80 per cent load read lower than the heavy element. The meter had been correctly connected when installed. Later both methods given above to determine the power factor of a three-phase circuit were applied, and both gave approximately 60 per cent power factor (at 30 per cent load).

182. To read correctly the consumption indicated on the dials of a recording watt-hour meter (sometimes, but erroneously, called a recording wattmeter) these directions should be followed (Rules and Regulations of the Commonwealth Edison Co., Chicago; see Fig. 83 for examples):

The pointer on the right-hand dial of a five-dial meter registers $\frac{1}{10}$ kw-hr. or 100 watt-hr. for each division of the dial. A complete revolu-

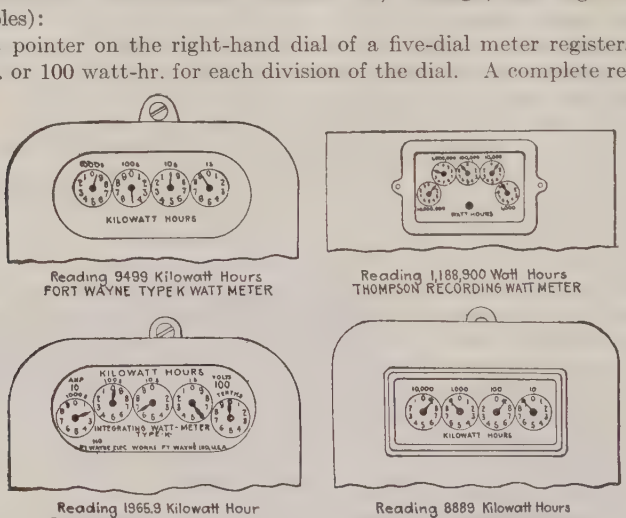


Fig. 83.—Examples of watt-hour meter readings.

tion of the hand on this dial will move the hand of the second dial one division and register 1 kw-hr. or 1,000 watt-hr. A complete revolution of the hand of the second dial will move the third hand 1 division and register 10 kw-hr. or 10,000 watt-hr. and so on.

Accordingly, read the hands from left to right and add two ciphers to the reading of the lowest dial to obtain the reading of the meter in watt-hours. Where there are four dials on the meter, the pointer on the right-hand dial registers 1 kw-hr. or 1,000 watt-hr. for each division of the dial, and it is necessary to add three ciphers to the reading of the lowest dial to obtain the reading in watt-hours, or the meter reads directly in kilowatt-hours.

Hands should always be read as indicating the figure which they have last passed, and not the one to which they are nearest. Thus, if a hand is very close to a figure, whether it has passed this figure or not must be determined from the next lower dial. If the hand of the lower dial has

just completed a revolution, the hand of the higher dial has passed the figure, but if the hand of the lower dial has not completed a revolution, the hand of the higher dial has not yet reached the figure, even though it may appear to have done so.

When one pointer is on 9, special care must be taken that the pointer on the next higher dial is not read too high, as it will appear to have reached the next number, but will not have done so until the hand at 9 has come to zero.

The hands on adjacent dials revolve in opposite directions. Therefore a reading should always be checked after being written down, as it is easy to mistake the direction of the rotation.

To determine the consumption for a given time, subtract the reading at the beginning of the period from the reading at the end. Always observe if a constant is marked at the bottom of the dial plate. If so, the difference of the readings must be multiplied by this constant to obtain the consumption.

183. The Wheatstone bridge is an instrument for measuring medium and high resistances. It is not suitable for measuring resistances of less than 1 ohm. An elementary diagram is shown in Fig. 84. R_1, R_2, and R are adjustable resistances, R_x is the unknown resistance, and G is a delicate galvanometer. A battery supplies e.m.f. It can be shown that if, when both keys are pressed, the galvanometer shows no deflection, then

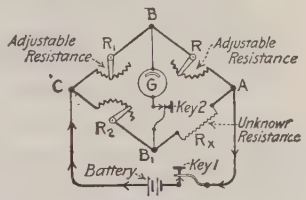


FIG. 84.—Elementary diagram of the Wheatstone bridge.

$$\frac{R_1}{R} = \frac{R_2}{R_x} \quad \text{or} \quad R_x = \left(\frac{R_2}{R_1}\right) R \tag{74}$$

Example.—If $R_2 = 100$ ohms, $R_1 = 10$ ohms, and $R = 672$ ohms, what is the value of the unknown resistance?

Solution.—Substitute in the formula:

$$R_x = \left(\frac{R_2}{R_1}\right) R = \left(\frac{100}{10}\right) 672 = 10 \times 672 = 6{,}720 \text{ ohms}$$

The unknown resistance is 6.720 ohms.

In commercial bridges, the adjustable resistances R_2 and R_1 are usually so arranged that the ratio R_2/R_1 will be a fraction like $\frac{1}{10}$ or $\frac{1}{100}$ or a number like 10 or 100 so that R_x can be obtained readily by dividing or multiplying R by an easily handled number. R_1 and R_2 are sometimes called the ratio arms, and R is called the rheostat arm. For most accurate results the resistances R, R_1, and R_2 should be as nearly as possible equal to R_x.

184. A diagram of a commercial bridge of the post-office pattern is shown in Fig. 85. Its principle is similar to that of Fig. 84. Brass plugs are used to vary the resistance in arms R, R_1, and R_2. When a plug is inserted in the opening between two resistance coils it shunts out the coil. In using this bridge the ratio R_2/R_1 is arranged by the operator, depending upon the relative value of R_x as compared with R. Then R is adjusted until a balance is obtained. When R_x is greater than R the ratio must be 10, 100 or 1,000, and when R_x is smaller than R the ratio must be 0.1 or 0.01 or 0.001. If $R_1 = R_2$ the value of R_x equals R.

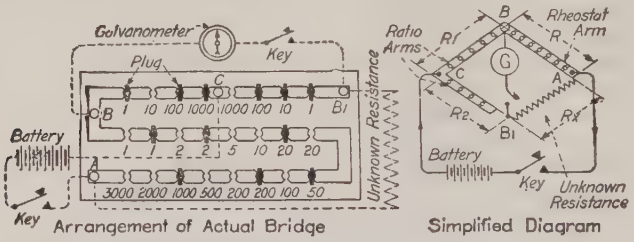


Fig. 85.—Post-office pattern of Wheatstone bridge.

185. Directions for Using a Wheatstone Bridge.—(1) Insert the unknown resistance. (2) Make a mental estimation of the probable value of the unknown resistance. If it is not greater than the total resistance in the arm R or smaller than that of any one coil in R, R_1 and R_2 may be made equal by taking plugs from the proper holes. (3) Take a plug from a coil, in R, of about the estimated resistance of R_x and press the keys. Note the deflection of the needle, whether it is to the right or left. Now unplug a coil in R of about twice the resistance of the first one unplugged. If the needle now deflects in the opposite direction the value of R_x lies between these two values. If the deflection is in the same direction the unplugged resistance in R is too great, and a value of about one-half that originally selected should be tried. Systematically narrow down the limits until the best possible balance is obtained. (4) Usually it is impossible to secure an exact balance. When this is the case proceed as indicated in the following example: Assume that the coil of smallest resistance in the R arm is of 0.1 ohm. With this added the galvanometer deflects two divisions to the right. The deflection without is three divisions to the left. Therefore a difference of 0.1 ohm makes a difference of five scale divisions. The resistance that would give no deflection is $\frac{3}{5} \times 0.1 = 0.06$ ohm. (5) Be careful not to allow the metal parts of the bridge plugs to become wet or greasy from the hands. (6) Use a twisting motion when inserting the plugs. Put them in firmly but do not use enough force to twist off the insulating handles. (7) When closing the keys, close the battery key first and in opening the keys open the galvanometer key first.

186. Locating Faults in a Cable (Standard Underground Cable Co.).—Figure 86 shows a simple method, using a dynamo, a galvanometer, and 10 or 15 ft. of bare wire. This method is only applicable when both conductors of the cable are of the same size. After making the connections shown it is only necessary to move the stylus b along the bare wire until the galvanometer is not deflected in either direction.

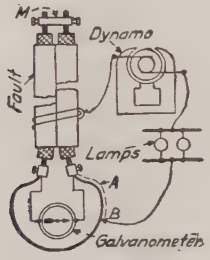


FIG. 86.—Locating a fault in a cable.

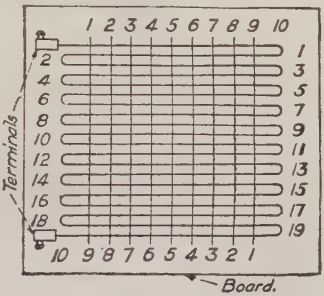


FIG. 87.—Homemade wire bridge.

Let A = the length of the wire between the balance point B and the faulty conductor, C = the total length of the wire, and L = the total length of the cable circuit = twice the length of the cable. Then distance to the fault = $(A \times L)/C$.

Figure 87 shows a simple form of wire bridge which can be used for tests of this kind. The length A can be read directly, and the value of C is 200. A telephone receiver may be used in place of the galvanometer.

187. Testing Cable Insulation with a Telephone Receiver and Battery (Standard Underground Cable Co.).—An extremely simple way to determine whether or not the insulation resistance of any particular wire is high is as follows: A telephone receiver and battery are connected as shown in Fig. 88. One side of the battery is attached to the lead sheath of the cable or to ground, and the other side to a telephone receiver. A rubber-insulated wire is attached to the other side of the telephone. To test, press the telephone receiver to the ear and touch the wire L to the conductor E; a click will always be heard the first time. After keeping both wires in contact for several seconds, break and make the connection once more; if no sound is heard at the instant of reconnection the wire is not faulty. With intervals of time between break and make of 1 sec. with a battery of 1 volt it can be assumed that no click indicates at least a resistance of 50 megohms. When more battery is used this number is increased about in proportion to the number of cells. Care must be

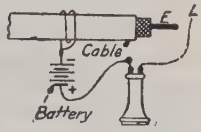


FIG. 88.—Test for insulation resistance.

taken that sounds in the telephone due to induction are not misconstrued for those produced by leaks.

188. Grounds on series lighting circuits frequently reveal their locations automatically. If there are two good grounds on the circuit the lamps connected in the line between the grounds will not burn because the grounds will shunt them out. For example, in Fig. 89 with a good ground at 1 and 11, lamps 2 to 10 would be shunted out. Sometimes there may be two grounds on a circuit, but they may not be "good" enough to shunt out the lamps. (This paragraph and those that follow on testing series circuits are from *Electrical World.*)

The presence of but one ground on a circuit, irrespective of how "good" it is, will not reveal itself automatically, and the proper operation of the circuit will not be affected by one ground. However, where there is one ground, it constitutes a serious menace to the lives of the station operators and trouble men. Furthermore, another ground may occur at any time

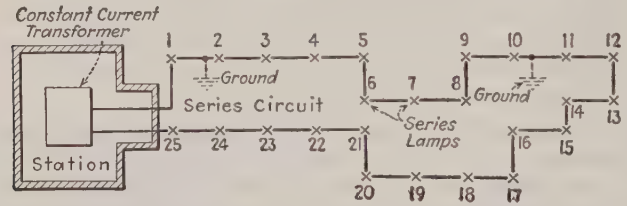


FIG. 89.—Effect of two grounds on a series circuit.

that may cause the shunting out of lamps or possibly a fire or destruction of equipment. Hence, it is very desirable to maintain the circuits entirely clear of grounds. It is the practice in all well-maintained stations to test each series circuit for grounds, some time during every afternoon, and if a ground is discovered a trouble man is sent out to locate and clear it before the circuit is thrown into service for the night.

189. The usual method of testing dead series circuits for grounds is to disconnect the circuit from all station apparatus and then to connect one terminal of a magneto test set to the circuit and the other to ground. If the bell rings vigorously when the crank is turned, the circuit is grounded. If it does not, the circuit is clear. If the circuit is very long or in cable for a considerable portion of its length, the bell may ring a little even if the circuit is clear of grounds.

190. The method of locating a ground on a dead series circuit is illustrated in Fig. 90. Disconnect all station apparatus and temporarily ground one side of the circuit as at *B* (Fig. 90). Proceed out along the line and connect some testing instrument (a magneto test set is most frequently used) in series with the circuit at some point. If, when the crank is turned, the magneto bell rings, indicating a closed circuit, the tester is between the station ground and the ground on the circuit. If the

magneto rings open, the tester is between the circuit ground and the ungrounded station end of the circuit. If in Fig. 90 the test is inserted at lamp 1, 2, or 3, the magneto should ring closed, while if inserted at any of the other lamps it should ring open.

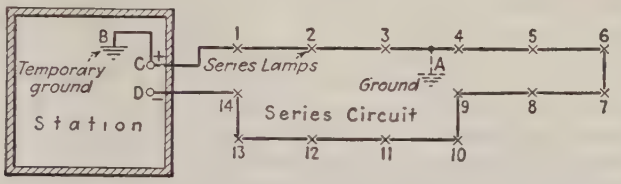


FIG. 90.—Locating a ground on a dead series circuit.

191. In locating either a ground or an open on a series circuit, unless the tester has an idea as to the location of the trouble, he should proceed first to the middle point of the circuit and there make his first test. This first test will indicate on which side of the middle point the trouble is. He should then proceed to the middle point of the half of the circuit that shows trouble and there make another test. This will localize the trouble to one quarter of the circuit. This "halving" of the sections of the circuit should be continued until the trouble is finally found.

If there is more than one ground on a series circuit the trouble is tedious to locate. If the tests made at different points on the circuit are confusing, indicating the existence of several grounds, the best procedure is to open the circuit into several distinct sections and then test each one as a unit, following the methods described in preceding paragraphs.

192. A ground on a series circuit can sometimes be located with the current from the transformer, by placing a temporary ground on the circuit at the station. For example, if in Fig. 90 a temporary ground is connected to terminal *B* and the device that supplies the operating current to the circuit is connected to terminals *C* and *D* and normal operating current thrown out on the circuit, lamps 1, 2, and 3 will not burn, indicating that the ground is between lamps 3 and 4. The use of this method is attended by some fire risk; hence, the method should be used with caution.

193. A method of locating a ground on a series circuit with a lamp bank is suggested in Fig. 91. A bank of 110-volt incandescent lamps, each of the same wattage, is connected in series as indicated, and one end of the bank is permanently grounded. There should be a sufficient number of lamps in the bank so that the sum of the voltages of all of the lamps is at least equal to the voltage impressed on the series circuit by the transformer. For instance, if the voltage impressed on the series circuit is 6,600, there should be at least sixty 110-volt incandescent lamps in the bank ($6{,}600 \div 110 = 60$).

In locating a ground, the flexible cord which is connected to the center point of the double-throw switch is successively placed on different points

on the conductor that connects the incandescent lamps in series, the switch being thrown to one or the other of the circuit terminals *C* or *D*. Move the flexible cord along until the incandescent lamps in the bank, between the point of connection of the cord and the permanent ground, burn at about full brilliancy. When this condition obtains, the voltage impressed across the lamps that are burning fully brilliant is approximately equal to the voltage impressed on the portion of the circuit (to which the switch connects) between the station and the ground. The voltage required across each lamp of the outside circuit being known, the number of lamps between the station and the ground can be readily computed, and thereby the ground is located.

Great care must be exercised in using this method. Practically all series lighting circuits operate at very high voltage. Hence, when the

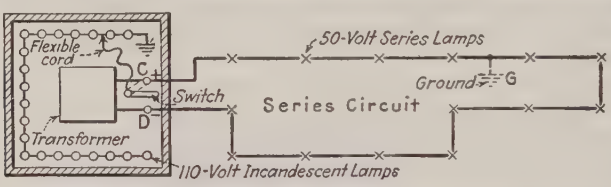


FIG. 91.—Locating a ground on a "live" series circuit with an incandescent lamp bank.

flexible cord is being moved along the lamp bank, the transformer should be entirely disconnected. If it is not, voltage dangerous to life is present.

Example.—Consider Fig. 91. There is a ground on the circuit. It is found that two of the incandescent lamps of the bank burn at full brilliancy between the flexible-cord connector and the lamp-bank ground. Since 110-volt lamps are used in the bank the voltage across these two is 220. This means that the voltage on the circuit between points *C* and *G* is about 220. Since the series lamps each require about 50 volts, there must be $220 \div 50 = 4.4$, or in round numbers 4, series lamps between *C* and the ground *G*. After making a test with the switch point on *C*, it should be thrown over to *D*, and a check test made from the other end of the circuit. The method of figuring is the same in each case.

194. To locate an "open" on a series circuit, ground one end of the circuit at the station as in Fig. 90. Then make tests at different points out on the circuit with the magneto connected in between line and ground. So long as the magneto bell indicates a closed circuit, the open is on the line side of the tester. When the magneto indicates an open circuit the open is toward the station from the tester.

195. The testing out of a concealed wiring system for proper connections is illustrated in Fig. 92. It is assumed that the wires are installed and that the locations of their runs are concealed by the plastering. Only the ends of the conductors are visible at the outlets. It is necessary to identify the conductor ends at each outlet. These tests are usually made with an electric-bell outfit (Fig. 61) because the sound of the bell will

indicate a closed circuit to the wireman in a distant room. Hence, one man can test out such a system. In testing out, first skin the ends of all of the conductors and see that none is in contact with any other or with the outlet box. Next, select a pair of conductors (*A*, Fig. 92), preferably the pair that serves the group, and connect the bell outfit to the ends of the pair as shown. Then proceed to the outlet (*B*, Fig. 92) at which the

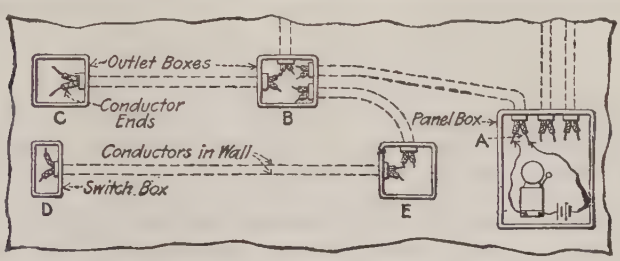


Fig. 92.—Testing out wiring for proper connections.

pair of conductors should terminate and successively touch together the ends of all the wires that terminate in that box until a pair is discovered whose ends touched together ring the bell. This identifies one pair. Tag this pair so that it can be readily found again and repeat the process on some other pair. Continue this until all of the conductors are identified. (These paragraphs on practical electrical tests are from *Electrical Engineering.*)

196. The method of testing out the connections for three-way switches is shown in Fig. 93. When finally connected, the circuits should be as

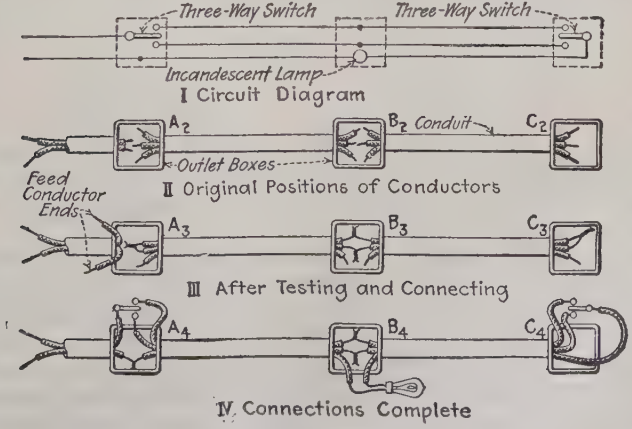


Fig. 93.—Testing out three-way switch connections.

shown at I. It is assumed that the conductors are in place and concealed within walls or ceilings and that only the ends are visible at the outlets, as at Fig. 93, II. First, identify the feed conductors and bend back their ends at the outlet box as at A_3. Next, twist together, temporarily, the bared ends of any two of the conductors at each of the switch outlets as at A_3 and C_3. The conductors having their ends thus twisted together will be the switch conductors. Now, at the lamp outlet, or outlets, identify the short-circuited switch conductors as directed in a preceding paragraph and connect and solder these switch conductors together as at B_3. Connect the remaining conductor ends at the lamp outlets to the lamps, B_4, connect one of the feed conductors to the center point of the three-way switch (A_4), and connect the other feed conductor to the lamp wire. The switch conductors are connected to the two points of the switch. At C_4 the same procedure is followed.

197. In testing out a new wiring installation for faults each branch circuit, main, and feeder should be treated individually. It is usually impracticable to test an installation as a unit, as open switches and loose connections in cutouts may render such a test worthless. If a test is made from the cutout, on the two conductors of each individual circuit, the above-mentioned possible elements of uncertainty are eliminated. Test each side of each circuit separately unless the lamps are in position.

198. Open circuits in multiple wiring installations are usually readily located. If the lamps are in position and lighting voltage available, it can be impressed on the circuit. The lamps on the generator side of the "open" will then burn while those on the far side will not, which localizes the open. Where lighting voltage is not available, all the lamps can be taken out of the sockets, and each of the sides of the circuit can be grounded at the cutout. Then a telephone-and-battery, a bell-and-battery, or a magneto test set can be connected temporarily and successively between one line and ground and between the other line and ground at each outlet on the branch. When the test set indicates an open circuit, the "open" is between the tester and the ground made at the cutout.

199. The test for short circuits on a multiple system is made by temporarily connecting a test set across the terminals of each branch circuit at the cutout. If there is a short circuit on the lines under test, its presence will be immediately evident by the indication of a closed circuit.

200. The test for continuity of multiple wiring circuits is made by temporarily connecting a test set across the terminals of each branch cutout and successively short-circuiting, one at a time, the sockets of the branch with a screw driver, a nail, or other metal object. The test set will then indicate whether the wiring of the circuit is open or closed. Where lighting voltage is available and plug cutouts are used, a lamp can be screwed into one socket of the cut-out and a plug fuse into the other. Then the tester can proceed from socket to socket and short-circuit each.

Where circuit to the socket is continuous, the lamp will light when the socket is short-circuited.

201. The test for grounds on a multiple wiring installation is made by temporarily connecting between line and ground a test set of one of the types hereinbefore described. If the test set indicates a closed circuit, the line being tested is grounded.

202. The testing of three-wire circuits to identify the neutral is effected as suggested in Fig. 94. Where the neutral is grounded, a test

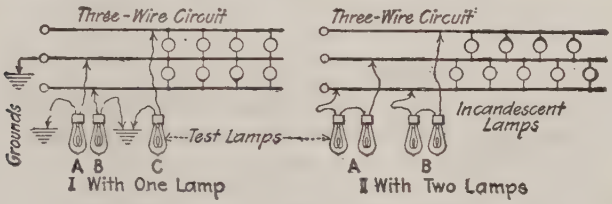


FIG. 94.—Locating neutral wire with test lamp.

lamp can be successively connected between each of the three conductors and ground (Fig. 94, I). When the ungrounded side of the lamp is touched to the neutral wire it will not burn, but when touched to either of the outside wires it will burn. A method that can be used with either a grounded or an ungrounded neutral is illustrated in Fig. 94, II. Connect the two test lamps in series successively between one of the line wires and the other two. When connected across the two outer wires both lamps will burn at full voltage, but when connected between one of the outer wires and neutral they will burn at only half voltage. The touching test described in Sec. **154** can also be applied.

203. The testing of lighting fixtures prior to installation is best accomplished with a voltmeter (Fig. 95). The test for short circuit and

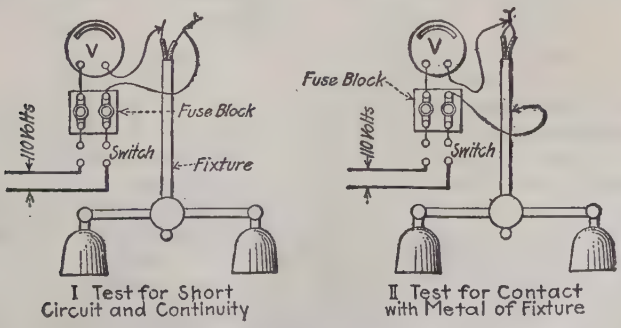


FIG. 95.—Methods of "testing out" fixtures.

continuity is illustrated at I. If the voltmeter does not give a reading with the lamps out of the sockets, the fixture wiring is clear of short

circuits. After the test for short circuits has been made, each socket is short-circuited with a metal object—a screw driver is frequently used—and if the voltmeter indicates the full voltage of the circuit each time a socket is short-circuited, it signifies that the circuit to that socket is continuous.

The fixture can be tested for grounds as at Fig. 95, II. If there is no deflection of the voltmeter with one lead from the voltmeter touching the metal work of the fixture and the other successively each of the fixture conductors, the fixture is clear of grounds. Be certain that one voltmeter terminal is in actual contact with the metal work of the fixture and not insulated therefrom by the lacquer finish. This test should be made with the lamps out of the socket.

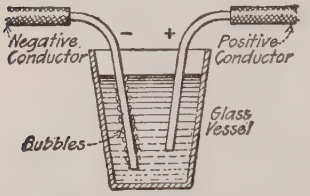


Fig. 96.—Determination of polarity with conductor ends in water.

204. To determine the polarity of d-c circuits hold the two conductors in a glass vessel of water as in Fig. 96. It may be necessary to pour a little common salt or acid into the water to render it conducting. Pure water is a poor conductor. Bubbles will form only on the negative conductor, indicating the presence of current and the polarity of the circuit. Be careful not to touch the conductor ends together and cause a short circuit (see also Fig. 97, and neon testers, Sec. **163**).

205. The direction of current flow in a d-c circuit can be determined with a compass as described in Sec. **61**.

206. Ground detectors are desirable on ungrounded systems in order that when an accidental ground occurs it can be remedied before a second ground on another wire causes a short circuit. Control circuits especially should be suitably equipped with ground detectors, as a double ground may cause the closing or tripping of circuits carrying load, with serious consequences.

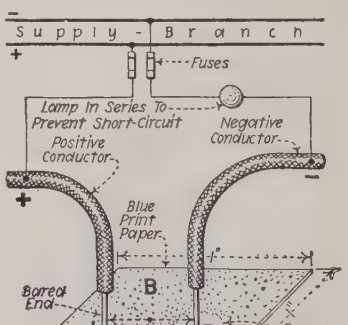


Fig. 97.—Blueprint paper used for testing polarity.

207. Ground Detectors for Two-wire, D-c Circuits.—Figure 98 shows a very good and simple detector for any two-wire low-voltage system. The lamps for the detector should each be of the same wattage and voltage—the voltage being about the same as that of the regular lamps in the plant—and two lamps should be selected which, when connected

in series, burn with equal brilliancy. Although somewhat greater sensitiveness can be obtained with low-wattage lamps, such as 25-watt, for example, it is believed in general to be preferable to use lamps of same wattage as those throughout the plant, as then a burned-out or broken detector lamp can be immediately replaced by a good lamp from the regular stock, thus avoiding the necessity of keeping on hand a few spare special lamps.

The detector lamps, being two in series across the proper voltage for one lamp, burn only dimly. If, however, a ground occurs on any circuit, as at *a*, the current from the positive bus bar through lamp 1 divides on reaching *b*, instead of all going through lamp 2, as it did when there was no ground. Part now goes down the ground wire and through the ground to *a*, as indicated by the broken line, and thence through the wires to the negative bus bar. This reduces the resistance from *b* to the negative bus bar, and therefore more current flows through lamp 1 than before, while less current flows through lamp 2. Lamp 1 consequently brightens and lamp 2 dims. If the ground had occurred at *c* instead of *a*, lamp 2 would have brightened and lamp 1 would have dimmed.

Attention is called to the following points, which are frequently neglected in this form of detector:

1. The lamp receptacles should be keyless, and there should be no switches of any kind in any of the connecting wires, so that the detector will always be in operation. In order to be of the greatest value, the indications must be given instantly when a ground occurs. The observer should not have to wait until the engineer or electrician remembers to close a switch.

2. The wires should be protected by small fuses where they connect to the bus bars. If these fuses are omitted, a short circuit across these wires would either burn up the wires or blow the main generator fuses.

3. The lamps should be placed very close together, within 1 or 2 in. of each other if possible. The farther apart they are, the harder it is to detect any slight difference in brilliancy between them.

4. The ground wire should be carefully soldered to a pipe which is thoroughly connected to the ground, or some other equally good ground connection should be provided.

208. A lamp ground detector for a three-wire Edison system is shown in Fig. 99. In principle it is exactly the same as the two-lamp detector of Fig. 98. Its indications are as follows:

Switch on point 1	Ground at *a*—A bright, B and C dim.
	Ground at *b*—B and C bright, A dim.
	Ground at *c*—A bright, B and C dim.
Switch on point 2	Ground at *a*—A and B bright, C dim.
	Ground at *b*—C bright, A and B dim.
	Ground at *c*—C bright, A and B dim.

With the lamp switch at point 1, grounds at *a* and *c* give the same indication, but by throwing the switch to point 2 it will be at once evident whether the ground is on the positive or negative side. It is to remove the uncertainty which would otherwise exist that this switch is needed. It should have no "off" position.

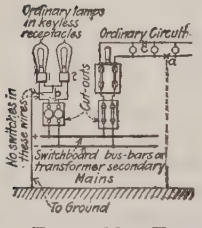


FIG. 98.—Two-lamp ground detector.

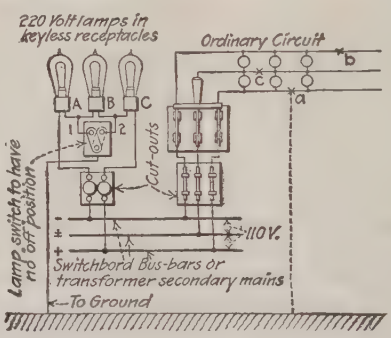


FIG. 99.—Lamp ground detector for three-wire system.

The man in charge of a plant can readily familiarize himself with the indications of the detector by purposely putting a ground on the different wires and noting the indications.

If the neutral is permanently grounded, a ground detector is, of course, of no use.

209. The same degree of sensitiveness on both sides can be obtained by means of the lamp switch in Fig. 99, but for grounds on the neutral, there is never more than half the full voltage available to operate the lamps, so that the indications are necessarily less sensitive.

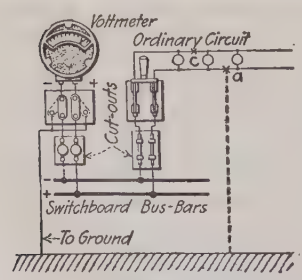


FIG. 100.—Voltmeter ground detector.

210. On d-c control circuits, a telegraph-type relay, which will sound an alarm, is preferable to the lamps, since sufficient current can flow through the lamps as a result of double grounds to operate some relays and cause circuit breakers to operate.

211. An ordinary voltmeter can be used as an intermittent ground detector on d-c circuits of any voltage, as shown in Fig. 100. The voltmeter ordinarily used to indicate the voltage on the system can, of course, be used for this purpose, the voltmeter switch shown in the cut being arranged to give the different desired connections.

If, for example, the system shown in Fig. 100 were of about 100 volts, the voltmeter would register 100 when the levers of the switch were on the inside contact points as shown. If, now, the right-hand lever were moved to the outside contact point as shown dotted, and there were a ground on the system, as at a, current would pass from the positive bus bar through the circuit to a, thence through the ground to the ground wire, and through the voltmeter to the negative bus bar, causing the voltmeter to read something below 100, unless the ground at a were practically a perfect connection. In that case the voltmeter reading would be 100. If the positive side of the system were entirely free from grounds, the voltmeter reading would be 0.

Assume that under these conditions the voltmeter reads 50, and that the resistance of the voltmeter itself is 20,000 ohms. Since with no external resistance, when the voltmeter is connected directly to the bus bars, it reads 100, while now it reads 50, the total resistance under the new conditions must be 40,000 ohms. The resistance of the ground at a is 40,000 − 20,000 = 20,000 ohms.

If the voltmeter had read only 20 the total resistance would have been $^{10}\!/_{20} \times 20{,}000 = 100{,}000$, and the resistance of the ground 100,000 − 20,000 = 80,000 ohms.

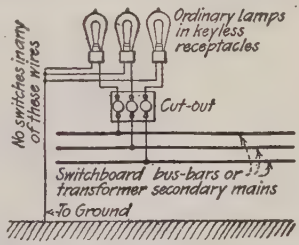


Fig. 101.—Three-phase lamp detector.

212. Ground Detectors for Ordinary Low-voltage Three-phase A-c Circuits. A lamp detector connected as in Fig. 101 may be used. The indication is the same as that with the lamp detectors described above. Thus, when a ground comes on one wire, the lamp attached to that wire dims and the other two brighten.

For ordinary two-phase (or quarter-phase) systems, where the phases are entirely insulated from each other, the two-lamp detector can be used, one detector on each phase. There are, however, in this class of wiring several complicated systems, to all of which the lamp detector principle is applicable, although the exact method of connections differs in each case, so that no general rule can be given.

213. Electrostatic ground detectors are used for high-voltage ungrounded a-c systems. This instrument for use on three-phase circuits consists of a semispherical vane flexibly supported (Fig. 102). Around the circumference of the vane are three stationary curved plates, each being connected through a capacitor to one of the three phase lines. The operation is due to the electrostatic field created between the plates. The vane is grounded, and a ground on any line removes the charge between the plate connected to that line and the ground. This causes the vane to move toward the other two plates against the action of a

spring. Thus the vane being off-center indicates a ground. The capacitors (Fig. 102) insulate the instrument from the high voltage of the line. A single-phase electrostatic ground detector is shown in Fig. 103.

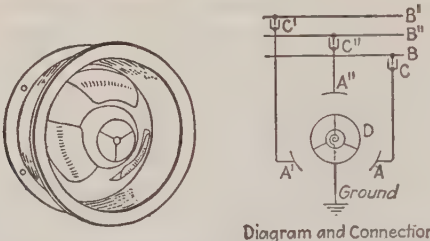


FIG. 102.—Three-phase electrostatic ground detector. (*Westinghouse Electric & Manufacturing Co.*)

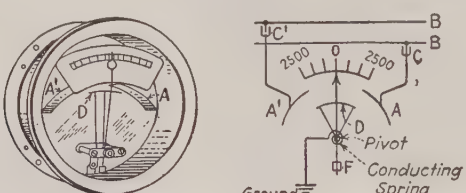


FIG. 103.—Single-phase electrostatic ground detector. (*Westinghouse Electric & Manufacturing Co.*)

214. A triplex voltmeter, which is an instrument containing three voltmeter movements with short scales (Fig. 104) may also be used on a-c systems. Each voltmeter is connected between one line and ground.

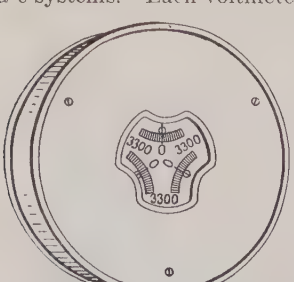


FIG. 104.—Electrostatic ground detector (triplex voltmeter type). (*General Electric Co.*)

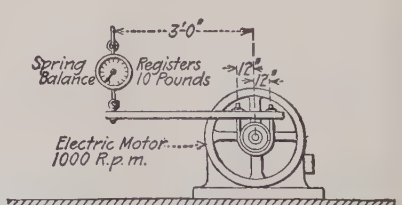


FIG. 105.—Horsepower determination with a prony brake.

With no grounds all voltmeters should read zero, but a ground on one line will cause the other two meters to read. The magnitude of the

reading will depend on the resistance of the meter and the resistance of the ground, a good ground being indicated by full line-voltage reading.

215. Test to Determine Horsepower of an Electric Motor.—Applying the principles, outlined elsewhere in this division, to a motor under test for output, the power delivered being measured with a prony brake (Fig. 105) may be taken as an example.

Example.—The torque is 10 lb. at 3-ft. radius, or 30 lb.-ft., or 30 lb. at 1-ft. radius. Since the motor pulley is turning at the rate of 1,000 r.p.m., a point on its circumference travels $2\pi R = 2 \times 3.14 \times 1 \times 1000 = 6{,}280$ ft. per min. At its circumference the pulley is overcoming a resistance of 30 lb. Therefore it is doing work at the rate of $30 \times 6{,}280 = 188{,}400$ ft.-lb. per min. Since, when work is done at the rate of 33,000 ft.-lb. per min., a horsepower is developed, the motor is delivering $188{,}400 \div 33{,}000 = 5.7$ hp. It should be noted that, though the torque at the circumference of the motor pulley was considered in the example, it is not necessary to take the torque at that point. The torque may be taken at any point if the radius to that point is used instead of the radius of the pulley. The formula for determining the horsepower output of a motor under test with a prony brake is

$$\text{Hp.} = 2 \times \pi TS \div 33{,}000.$$

where $\pi = 3.1416$; T = torque in pounds-feet; and S is the speed of the motor in r.p.m. Substituting the values from the above example in this formula

$$\text{Hp.} = 2 \times 3.14 \times 30 \times 1{,}000 \div 33{,}000 = 5.7 \text{ hp.}$$

This is the same result secured by the former and longer method. In metric units, work is expressed in kilogram-meters, so, conversely, torque should be expressed in meter-kilograms or in kilograms at a given radius in meters.

216. The testing of motors and generators for faults is treated in Div. 7 on Motors and Generators.

DIVISION 2

PROPERTIES AND SPLICING OF CONDUCTORS

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ELECTRICAL CONDUCTING WIRES AND CABLES

1. Electrical conducting wires and cables are available in a great variety of different types and forms of construction. To cover this one subject completely would require a large volume. The aim of the author has been, therefore, to include in this division sufficient general information with respect to the materials employed, method of construction, and types available, so that it will enable a person to select intelligently the proper cable for a given application. At the end of the section, more detailed tabular information is included for the types of cables that the average worker will use most frequently.

2. Electric Wire and Cable Terminology (*U. S. Bureau of Standards Publication* 37).

Wire.—A slender rod or filament of drawn metal. (The definition restricts the term to what would ordinarily be understood by the term "solid wire." In the definition, the word "slender" is used in the sense that the length is great in comparison with the diameter. If a wire is covered with insulation, it is properly called an insulated wire, although primarily the term "wire" refers to the metal, nevertheless when the context shows that the wire is insulated the term "wire" will be understood to include the insulation.)

Conductor.—A wire or combination of wires not insulated from one another, suitable for carrying a single electric current. (The term "conductor" is not to include a combination of conductors insulated from one another, which would be suitable for carrying several different electric currents. Rolled conductors, such as bus bars, are, of course, conductors but are not considered under the terminology here given.)

Stranded Conductor.—A conductor composed of a group of wires or any combination of groups of wires. (The wires in a stranded conductor are usually twisted or braided together.)

Cable.—(1) A stranded conductor (single-conductor cable), or (2) a combination of conductors insulated from one another (multiple-conductor cable).

The component conductors of the second kind of cable may be either solid or stranded, and this kind of cable may or may not have a common insulating covering. The first kind of cable is a single conductor, while the second kind is a group of several conductors. The term "cable" is applied by some manufacturers to a solid wire heavily insulated and lead covered; this usage arises from the manner of the insulation, but such a conductor is not included under this definition of "cable." The term

"cable" is a general one and in practice it is usually applied only to the larger sizes. A small cable is called a stranded wire or a cord, both of which are defined below. Cables may be bare or insulated, and the latter may be armored with lead or with steel wires or bands.

Strand.—One of the wires or groups of wires of any stranded conductor.

Stranded Wire.—A group of small wires, used as a single wire. (A wire has been defined as a slender rod or filament of drawn metal. If such a filament is subdivided into several smaller filaments or strands and is used as a single wire, it is called stranded wire. There is no sharp dividing line of size between a stranded wire and a cable. If used as a wire, for example in winding inductance coils or magnets, it is called a stranded wire and not a cable. If it is substantially insulated, it is called a cord, defined below.)

Cord.—A small cable, very flexible and substantially insulated to withstand wear. (There is no sharp dividing line in respect to size between a cord and a cable, and likewise no sharp dividing line in respect to the character of insulation between a cord and a stranded wire. Usually the insulation of a cord contains rubber.)

Concentric Strand.—A strand composed of a central core surrounded by one or more layers of helically laid wires or groups of wires.

Concentric-lay Cable.—A single-conductor cable composed of a central core surrounded by one or more layers of helically laid wires.

Rope-lay Cable.—A single-conductor cable composed of a central core surrounded by one or more layers of helically laid groups of wires. (This kind of cable differs from the preceding in that the main strands are themselves stranded.)

N-Conductor Cable.—A combination of N conductors insulated from one another. (It is not intended that the name as here given be actually used. One would instead speak of a 3-conductor cable, a 12-conductor cable, etc. In referring to the general case, one may speak of a multiple-conductor cable, as in definition for "cable" above.)

N-Conductor Concentric Cable.—A cable composed of an insulated central conducting core with tubular stranded conductors laid over it concentrically and separated by layers of insulation. (Usually only 2-conductor or 3-conductor. Such conductors are used in carrying alternating currents. The remark on the expression "N-conductor" given for the preceding definition applies here also.)

Duplex Cable.—Two insulated single-conductor cables twisted together. (They may or may not have a common insulating covering.)

Twin Cable.—Two insulated single-conductor cables laid parallel, having a common covering.

Triplex Cable.—Three insulated single-conductor cables twisted together. (They may or may not have a common insulating covering.)

Twisted Pair.—Two small insulated conductors twisted together, without a common covering. (The two conductors of a twisted pair are

usually substantially insulated, so that the combination is a special case of a cord.)

Twin Wire.—Two small insulated conductors laid parallel, having a common covering.

3. Wire Sizes.—The size of wire is usually expressed according to some wire gage. The different sizes are referred to by gage numbers. Unfortunately several different systems of gages have been originated by different manufacturers for their products. However, it has become standard practice in the United States to employ the American wire gage (A.w.g.), also known as the Brown and Sharpe (B. & S.) for the designation of copper and aluminum wire and cable used in the electrical industry. The names, abbreviations, and uses of the most important gages used for the measurement of wires and sheet-metal plates are given in Sec. 4. A numerical comparison of these gages is given in Table 80. It will be observed that in most cases the larger the gage number the smaller the size of the wire.

4. Names, Abbreviations, and Uses of the Principal Wire and Sheet-metal Gages

Col. No. in Table 80	Names and abbreviations		Ordinarily used for measuring
	Usual	Others	
1.	American wire gage (A.w.g.)	Browne and Sharpe (B. & S.)	Copper, aluminum, and other nonferrous wires, rods, and plates. Wall thickness of tubes.
2.	Steel wire gage (Stl. w.g.)	Roebling, American Steel and Wire, Washburn & Moen, National G. W. Prentiss	Iron and steel wire. Wire nails. Brass and iron escutcheon pins.
3.	Birmingham wire gage (B.w.g.)	Stubs Iron Wire Gage, Iron Wire Gage	Galvanized iron and steel wire. Iron rivets, copper rivets. Thickness of wall of nonferrous seamless tubing.
4.	Stubs steel wire gage	.....	Drill rod.
5.	British standard wire gage (S.w.g.)	Imperial Standard Wire Gage, Standard Wire Gage, English Legal Standard	Legal standard wire gage for Canada and Great Britain. Used sometimes by American telephone and telegraph companies for bare copper line wire.
6.	Steel music wire gage (M.w.g.)	Hammacher Schlemmer, Felten & Guilleaume	Steel music wire.
7.	United States standard (U.S.S.)	.....	Legal standard for iron and steel plate. Monel metal. Galvanized sheets.
8.	American Zinc	.....	Sheet zinc.
9.	Birmingham gage (B.g.)	.....	Legal standard for iron and steel sheets in Canada and England.

5. How to Remember the A.w.g. or B. & S. Wire-gage Table (Westinghouse Diary).—A wire that is three sizes larger than another wire has half the resistance, twice the weight, and twice the area. A wire that is ten sizes larger than another wire has one-tenth the resistance, ten times the weight and ten times the area. Number 10 wire is 0.10 in. in diameter (more precisely 0.102); it has an area of 10,000 cir. mils (more precisely 10,380); it has a resistance of 1 ohm per 1,000 ft. at 20°C. (68°F.), and weighs 32 lb. (more precisely 31.4 lb.) per 1,000 ft.

The weight of 1,000 ft. of No. 5 wire is 100 lb. The relative values of resistance (for decreasing sizes) and of weight and area (for increasing sizes) for consecutive sizes are 0.50, 0.63, 0.80, 1.00, 1.25, 1.60, 2.00. The relative values of the diameters of *alternate* sizes of wire are 0.50, 0.63, 0.80, 1.00, 1.25, 1.60, 2.00. To find resistance, drop one cipher from the number of circular mils; the result is the number of feet per ohm. To find weight, drop four ciphers from the number of circular mils and multiply by the weight of No. 10 wire.

FIG. 1.—Standard wire gage (greatly reduced).

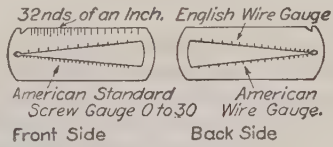


FIG. 2.—Angular wire gage (greatly reduced).

6. Wire measuring gages (Figs. 1 and 2) are made of steel plate. With the kind shown in Fig. 1 the wire being measured is inserted in the slots in the periphery until a slot is found in which the wire just fits. Its gage number is indicated opposite the slot. A measuring gage like that of Fig. 1 indicates the numbers of one gage or system only. A gage like that of Fig. 2 indicates the numbers of four gages but has the disadvantage that, to use it, the end of the wire must be available to push through the slot. The wire is pushed as far toward the small end of the slot as it will go, and its gage number will be indicated opposite the point where the wire stops. The gage of Fig. 2 is arranged to indicate gage numbers for the American screw gage, English wire gage, and American wire gage, and one scale is divided into thirty-seconds of an inch.

7. A micrometer is frequently used for determining the size of a given wire or cable. It provides an accurate means of measuring the diameter of the wire or cable to thousandths of an inch and estimating to ten thousandths. After having determined the diameter the corresponding gage size may be ascertained by referring to a wire table. The wire to be measured is placed between the thumbscrew and the anvil (Fig. 3), and the screw turned until the wire is lightly held between the screw and the anvil. The screw has 40 threads to the inch so that one complete

turn of the screw in a left-hand direction will open the micrometer $\frac{1}{40}$ of an inch. On the edge of the collar is a circular scale divided into 25 divisions; hence, when the screw is turned through one of these divisions, the micrometer will open $\frac{1}{25} \times \frac{1}{40}$ in. $= \frac{1}{1000}$ in. The shaft on which the collar turns is marked into tenths of an inch and each $\frac{1}{10}$ is subdivided into four parts. Each of these parts must be equal to $\frac{1}{10}$ in. by $\frac{1}{4} = \frac{1}{40}$ in. $= 0.025$ in. Therefore a complete rotation

FIG. 3.—A micrometer caliper.

of the collar or 25 of its divisions will equal one division of the shaft or 0.025 in.

8. To read a micrometer (see Fig. 4 and the paragraph above) note the number on the circular scale nearest the index line. This indicates the number of thousandths. Note the number of small divisions uncovered on the shaft scale. Each one of these small divisions indicates 0.025 in. ($\frac{25}{1000}$). Add together the number of thousandths indicated on the circular scale and 0.025 $\times$ the number of small divisions wholly uncovered on the shaft scale. The sum will be the distance that the jaws are apart.

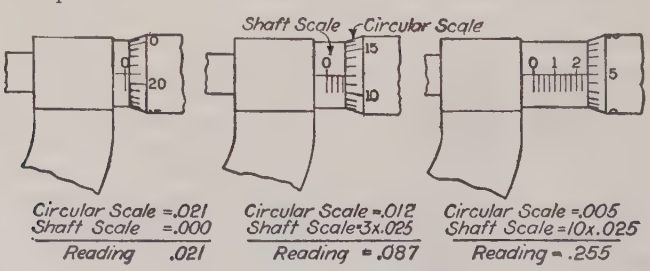


FIG. 4.—A micrometer caliper.

Examples are snown in Fig. 4.

9. Classification of Wires or Cables.—Electrical conducting wires and cables may be classified in several different ways depending upon the particular factor of consideration as follows:

1. According to degree of covering of wire or cable.
2. According to material and make-up of electrical conductor.
3. According to number of conductors in cable.

4. If insulated, according to insulation employed.
5. According to protective covering.
6. According to service.

10. Classification According to Degree of Covering.—Probably the broadest classification of electrical wires and cables is according to the degree of covering employed, as follows:

1. Bare.
2. Covered but not insulated.
3. Insulated and covered.

In many cases **bare** conductors without any covering over the metallic conductors are employed for electrical circuits. The conductors are supported on insulators so spaced depending upon the voltage of the circuit that the length of the air space between the conductors will provide sufficient insulation. Bare conductors are employed for the majority of overhead transmission lines. They are also used for certain overhead telephone and telegraph circuits. The National Electrical Code by special permission will allow bare conductors for feeder circuits not exceeding 600 volts provided they are installed in a chase, channel, or shaft of noncombustible material in a building of fire-resistant construction.

There is a definite distinction between the meaning of the words **covered** and **insulated** as applied in electrical cable terminology. **Insulated** wires and cables consist of an electrical conductor covered with some form of electrical insulation and an outer protective covering over the insulation. With **covered** wires the conductor is protected against mechanical injury by some form of covering applied directly over the conductor. This covering, however, does not provide insulation of the wet conductor to any great extent and often even becomes a fair conductor itself when moist. The covering cannot, therefore, be relied upon to afford consistently any insulation beyond that of the air spacing between the conductors.

11. Three types of covered wires are manufactured: weatherproof (W P), slow-burning (S B), and slow-burning weatherproof (S B W) (see item 1 in Table 139 for illustration). **Weatherproof,** more correctly called **weather-resisting,** wire and cable is the general standard for aerial distribution and low-voltage transmission circuits. It is also used for exposed interior wiring where the installation is exposed to corrosive vapors or moisture. **Slow-burning (heat-resisting)** wires and cables are employed for exposed interior wiring. The National Electrical Code permits their use for wiring in conduit, surface raceways, and electrical metallic tubing when the installation is exposed to temperatures exceeding those permitted for rubber- or varnished-cambric-insulated wires or cables. These cables should be used only in dry locations, and therefore they are not suitable for outdoor service. They should not be used where the temperature will exceed 194°F. (90°C.). **Slow-burning weatherproof** wires and cables were used to a considerable degree at one

time. They are now seldom used, and their manufacture has been discontinued by many companies. This type of covered wire or cable is allowed by the National Electrical Code for exposed interior wiring in dry locations where the temperature does not exceed 194°F. (90°C.). It is not suitable for outdoor service.

12. Weatherproof covered wire is available in two types. Both types are designated as U R C and are manufactured according to specifications recommended by the Utilities Research Commission. The two types are distinguished by at least one manufacturer as O. K.-U R C and Peerless U R C. The O. K. is the more common type. The wire is covered with two or three weatherproof cotton braids applied directly over the conductor. The braids are saturated with a black asphaltic compound. The outside surface of the outer braid is coated with mica flake to provide a smooth surface free of tackiness. The Peerless type is a better grade covering and in addition to its longer life characteristics provides some degree of over-all electrical insulation to the conductor. The construction consists of a compacted pad of unspun cotton wrapped helically directly around the conductor and filled with asphalt. This provides a homogeneous wall of insulation without the usual braid interstices encountered in ordinary weatherproof covered wire. The asphalt-impregnated cotton pad is covered with a standard outer weatherproof braid. Peerless wire is made in two types which are designated as double and triple braid. Actually there is only one braid in both types, but the combination of the cotton pad of different thicknesses, respectively, and the braid give a covering which is equivalent in thickness to the regular double- or triple-braid O. K. wires. Weatherproof covered wire is available with the conductor material consisting of copper, solid copperweld, solid bronze, composite copper-copperweld, all aluminum, or steel-reinforced aluminum (see Tables 140 to 143 for data).

13. Slow-burning weatherproof conductors have a covering consisting of an inner weatherproof coating and an outer heat-resisting coating. The National Electrical Code requires that the heat-resisting coating be six-tenth the thickness of the entire coating. To meet this condition the manufacturers use one weatherproof braid and two heat-resisting braids. The heat-resisting compound consists of a mixture containing white lead, oxide of zinc, chalk, or some similar substance. The outer braid is rubbed smooth on the outside and finished as for weatherproof covered wire.

Wires with a heat-resisting outer coating have the advantage that dust and lint do not readily adhere to their outer surfaces, as is often the case with weatherproofed braids. If dust does collect, it can be easily swept off. Slow-burning weatherproof wire is cheaper than slow-burning wire (see Table 141 for data and item 1 of Table 139 for illustration).

14. Slow-burning (heat-resisting) wire or cable is covered with three braids impregnated with a heat-resisting compound, as is used on the

outer braids of slow-burning weatherproof conductors. The outer braid is rubbed to a smooth hard white finish (see Table 140 for data and item 1 of Table 139 for illustration).

15. Material and Make-up of Electrical Conductors.—The conductor may consist of a single solid wire or a stranded cable made up of several individual bare wires twisted together. Stranded conductors are more flexible than a single solid wire. The flexibility of the cable increases with the number of strands and also depends upon the manner of arranging the individual strands in the make-up of the conductor. Solid wires are used for conductors of the smaller sizes and stranded cables for the larger sizes. In the intermediate sizes both solid and stranded conductors are available.

Electrical conducting cables are made of copper, aluminum, steel, bronze, or a combination of either copper or aluminum with steel. Copper is the material most commonly employed, owing to its high conductivity. Practically all insulated wires and cables employ copper conductors. Wires and cables made of aluminum or steel are frequently found to be more economical for certain classes of aerial construction. All-steel conductors are employed for telephone and telegraph work and certain rural distribution lines with light load densities. Steel-copper conductors are employed for long-span river crossings of power lines and for certain rural distribution lines.

A classification of electrical conductors with respect to standard materials and make-ups available is given below:

A. Copper.
- 1. Solid.
  - *a*. Round.
  - *b*. Grooved.
  - *c*. Figure eight.
  - *d*. Figure nine.
  - *e*. Square or rectangular.
- 2. Standard concentric stranded.
  - *a*. Class AA.
  - *b*. Class A.
  - *c*. Class B.
  - *d*. Class C.
  - *e*. Class D.
- 3. Standard rope stranded.
  - *a*. Class G.
  - *b*. Class H.
  - *c*. Class J (Bunched-stranded ropes).
  - *d*. Class L (Bunched-stranded ropes).
- 4. Bunched stranded.
- 5. Annular concentric stranded.
- 6. Special stranded.
- 7. Compack stranded.
  - *a*. Round.
  - *b*. Sector.
  - *c*. Segmental.
- 8. Hollow-core stranded.
- 9. Tubular segmental (Type HH).

B. Iron or steel.
- 1. Solid.
- 2. Stranded.

C. Copper-steel.
- 1. Copperweld.
  - *a*. Solid.
  - *b*. Stranded.
- 2. Copperweld and copper.
- 3. Copper and steel stranded.

D. Aluminum (stranded).

E. Aluminum and steel. (ACSR.). *F.* Bronze.

Refer to Table 81 for illustrations and applications of different make-ups. Refer to Table 82 for guide to applications of conductor materials.

16. Copper wire is made in three grades of hardness known as **hard-drawn, medium hard-drawn,** and **soft** or **annealed.** Hard-drawn wire has the greatest tensile strength and the least amount of elongation under stress and is the stiffest and hardest to bend and work. Soft-drawn or annealed wire has the lowest tensile strength and the greatest elongation under stress and is very pliable and easily bent. Medium hard-drawn wire has characteristics intermediate between those of hard-drawn and soft-drawn wire. The conductivity of copper wires decreases slightly as the degree of hardness increases. However, there is relatively little difference in the conductivity of the different grades.

Hard-drawn wire is used for long-span transmission lines, trolley contact wires, telephone wires, and other applications where it is desirable to have the highest possible tensile strength.

Medium hard-drawn wire is employed for such applications as short-span distribution circuits and trolley feeders, where slightly lower tensile strength is satisfactory and greater pliability is desired.

Soft-drawn or annealed copper is used for all covered or insulated copper conductors except weatherproof covered cables. Wires with this covering are available in all the three grades of hardness of copper. Bare or weatherproof covered soft wire is used only for short spans.

Copper wire used for rubber-insulated cable must be **tinned** by coating with pure tin in order to protect the copper against chemical action caused by contact with the rubber.

17. Make-up of Copper Conductors.—Copper conductors are manufactured in various forms of make-up as listed in Sec. **15,** depending upon their size and application. An understanding of the construction of the different make-ups and their applications can be gained from Table 81. The employment of solid or stranded conductors and the class of stranding used depend upon the degree of flexibility desired. Tables 85 to 91 give information on the standard strandings. For very flexible cables for special applications, special strandings are employed. There is no fixed standard for these special strandings, practice varying with different manufacturers. Data for bare copper conductors of the different standard make-ups are given in Tables 84 to 95.

18. Iron or Steel Electrical Conductors.—All-steel conductors for power circuits are made from special low-resistance high-strength steel stock. They are available in both solid and three-strand construction. Each wire is protected by a heavy galvanized coating of zinc. Since the economical field of application of all-steel conductors is only for light electrical loads, these conductors are manufactured in only three standard sizes (see Table 97). The stranded conductors are used in preference to the solid wires for longer span construction, owing to their inherent

damping capacity which reduces the amplitude of their vibration in strong lateral winds.

Commercial galvanized iron wire for telephone and telegraph circuits is made in three types designated as Extra Best Best (E.B.B.), Best Best (B.B.), and steel (see Table 96). These designations are somewhat misleading. They were adopted many years ago and refer to the electrical conductivity of the different grades. All three types are made from high-grade materials, and the same standard of galvanizing.

Extra Best Best wire has the best conductivity but the lowest tensile strength. Its weight per mile-ohm is from 4,700 to 5,000 lb. It is uniform in quality, pure, tough, and pliable. It is largely used by commercial telegraph companies, in railway telegraph service, for tie wires, and for signal bonding.

Best Best wire has a lower value of conductivity but greater tensile strength. Its weight per mile-ohm is from 5,600 to 6,000 lb. This grade is very largely used by telephone companies.

Steel is a stiff wire of high tensile strength and low conductivity. It is very difficult to work but is used on short lines that must be erected at low cost, where conductivity is of little importance. Its weight per mile-ohm is 6,500 to 7,000 lb.

19. Copper-steel Conductors.—Electrical conductors consisting of a combination of copper and steel are frequently employed for certain types of circuits (see Sec. **15** and Tables 82 and 105). Three general types of construction are listed in Sec. **15** and are illustrated in Table 81.

Copperweld wire is composed of a steel core with a copper covering thoroughly welded thereto by a molten welding process. This process produces a permanent bond between the two metals which prevents any electrogalvanic action and which will withstand hot-rolling, cold drawing, forging, bending, twisting, or sudden temperature changes. This wire is made in three grades: 30 per cent conductivity, extra high strength; 30 per cent conductivity, high strength; and 40 per cent conductivity, high strength (see Table 104). Solid conductors are made in sizes from No. 12 to No. 4/0 A.w.g. (see Table 105). Concentric stranded cables are available in sizes with outside diameters from 0.174 to 0.910 in. (see Table 108). Weatherproof covered copperweld solid wire is made in sizes from No. 12 to No. 2 A.w.g. Rubber-insulated twisted pair cables in size Nos. 14 and 17 are made for telephone, telegraph, and signal work. Single-conductor rubber-insulated wire may be obtained in any size. Rubber-insulated parallel drop wire is made in one size only, No. 17 A.w.g.

Composite cables (**copperweld and copper**) consisting of a combination of certain strands of copper wire with a number of strands of copperweld wire are often found to be economical for aerial circuits requiring more than average tensile strength combined with liberal conductance (see Table 107 for data).

Copper and steel cables consist of a combination of copper and steel wires stranded together. In the design of the cable the strands of the dif-

ferent materials are not intended to serve in any dual capacity. The conductivity of the cable is determined by the sectional area of the copper strands. The size of the cable is designated according to its total sectional area of copper, not according to the total sectional area of the whole cable. For instance, a cable designated as No. 4, consisting of two copper strands and one steel, has a total sectional area of 62,610 cir. mils and a sectional area of copper of 41,740. The area of the copper, 41,740 cir. mils, corresponds to the area of a No. 4 wire. The cable is, therefore, designated as a No. 4 cable, although its total sectional area of copper and steel is between that of a No. 3 and a No. 2 wire.

These copper and steel cables are available in sizes from No. 2 to No. 12. All sizes except Nos. 10 and 12 consist of two plain hard-drawn copper wires and one extra-galvanized steel wire. Wire cables of size Nos. 10 and 12 consist of one galvanized hard-drawn copper wire and two extra-galvanized steel wires (see Table 112 for data).

20. Aluminum and aluminum steel-reinforced conductors are often found to be economical for transmission and rural distribution circuits. Commercial hard-drawn aluminum wire has a conductivity at 20°C. of 60.97 per cent or a resistance of 17.010 ohms per cir. mil-ft. Its weight is 0.000000915 (or 91.5×10^{-8}) lb. per cir. mil-ft. An all-aluminum wire for equal conductivity must have a diameter 126 per cent and an area 160 per cent of that of a copper wire (see Table 109 for comparative values). All-aluminum conductors are available either bare or weatherproof covered. Stranded construction is always employed (data in Table 110). Aluminum steel-reinforced conductors, owing to their high tensile strength, are frequently used for long spans and for high-capacity lines requiring heavy conductors. They consist of a concentric stranded aluminum cable with a reinforcing steel core. Except in the smaller sizes the steel core is made up of several steel strands. Aluminum steel-reinforced conductors are available either bare or weatherproof covered (refer to Tables 111, 142, and 143 for data).

21. Number of Conductors.—Bare or covered (not insulated) cables must, of course, always be single conductor. Insulated cables are manufactured with one, two, three, and in some cases more conductors per cable. The choice between single- or multiple-conductor cable is affected by so many factors, which vary with the particular installation, that only some general suggestions can be made here. The selection will be influenced by the practical field conditions and facilities of installation, cost of cable and enclosure, physical dimensions of cable and of available enclosure, electrical load requirements, and the voltage and type of power supply system. Multiconductor cables usually result in lower cable cost, smaller voltage drop, and more economical utilization of duct space. On the other hand, single-conductor cables are more flexible and are easier to splice and install. For underground transmission and primary distribution applications, single-conductor cable is generally used when the voltage is above 35 kv. or when the load is 50,000 kva. or more. For all

other underground transmission and primary distribution applications, both single conductor and multiconductor, are employed. In the past the use of multiconductor cable was most common, but at present the practice of using single-conductor cable for this field is rapidly growing. Single-conductor cable is generally preferred for secondary distribution because of the ease in making taps. For interior building wiring, single-conductor cable is most commonly employed.

22. Cable Assembly.—In the application of electrical conducting wires and cables, it is essential to have a general knowledge of the materials employed in their manufacture and also of the manner of assembling the component parts in the manufacture of the finished cable. In the simple case of a bare wire the assembly is, of course, very simple, consisting only of the solid or stranded wire of the conductor. For insulated cables and especially for multiconductor ones the use of many materials and different forms of assembly is involved. The different component parts for the more common of insulated cables in the order that the parts are employed in the manufacture of the cable are as follows:

A. Single-conductor cables (see cables 2, 5, 9, 11, 12, 13, 17, and 20 in Table 139).
  1. Conductor.
  2. Insulation.
  3. Protective covering.

B. Multiconductor cables.
  1. Without shielding or belting (no insulation around group of conductors. See cables 3, 4, 6, 7, 9, 14, 22, 23, 24, 25, 26, 27, 28, 29, 30, 31, 32, 34, 36, 37, and 41 in Table 139).
    a. Conductor.
    b. Conductor insulation.
    c. Conductor covering.
    d. Fillers.
    e. Protective covering.
  2. Belted type (insulation around group of conductors. See cables 8, 10, and 18 in Table 139).
    a. Conductor.
    b. Conductor insulation.
    c. Conductor covering.
    d. Fillers.
    e. Belt insulation.
    f. Protective covering.
  3. Shielded type (see cables 19, 21, and 33 in Table 139).
    a. Conductor.
    b. Conductor insulation.
    c. Conductor shield.
    d. Fillers.
    e. Binder tape.
    f. Protective covering.

23. Electrical shielding is often necessary on power cable in order to confine the dielectric field to the inside of the cable insulation so as to prevent damage from corona or ionization. The shield usually consists of a thin (3 mils) conducting tape of copper or aluminum applied over the insulation of each conductor. The shielding tape sometimes is perforated to reduce power losses due to eddy currents set up in the shield. Sometimes a semiconducting tape of cotton with a conducting graphite coating is used. These semiconducting tapes are frequently employed for the shielding of aerial cable, since, owing to their adhering more closely to the insulation, they tend to prevent corona. Table 123 represents good practice with respect to shielding.

24. Fillers are used in the manufacture of most multiconductor cables. Their purpose is to fill up the spaces between the conductors in order to produce a solid round structure for the complete cable. The materials commonly employed for these fillers are, saturated jute, asbestos-base calk, rubber, and, in some cases, cotton.

25. Binder tapes are used in the construction of many multiconductor cables in order to bind the conductors, shields, and fillers together in proper form during the additions of the protective covering. The more common types of binder tapes employed are rubber-filled cloth tape, combinations of cotton cloth and rubber compounds, steel, and bronze.

26. Insulation of Electrical Conductors.—Except for aerial construction, interior exposed wiring on insulators, and special cases of interior-wiring feeder circuits, it is necessary to cover electrical conductors with some form of electrical insulation. An ideal insulating material for this purpose should have the following characteristics:

1. Long life.
2. Long-time high dielectric strength.
3. Resistance to corona and ionization.
4. Resistance to high temperature.
5. Mechanical flexibility.
6. Resistance to moisture.
7. Low dielectric loss.

It is impossible to find any one material that is best when all these essential characteristics are considered. For instance, impregnated paper has the highest electrical breakdown strength coupled with longest life of all the materials employed for the insulation of conductors. On the other hand, it is not moisture resistant, is not so flexible as some other materials, and will not withstand such high temperature as asbestos. Several different types of insulation are therefore employed. For each particular application the insulation should be selected whose over-all characteristics best meet the conditions of service encountered in that particular case. Section **29** gives a classification of the different types of insulation employed and a comparison of their general characteristics and recommendations with respect to temperature limitations.

27. Rubber Insulation.—At the present time rubber is the word used with respect to insulation to designate insulations consisting of compounds of natural rubber and or synthetic rubber, combined with such other ingredients as vulcanizing agents, antioxidants, fillers, softeners, and pigments. These natural rubber and synthetic rubberlike compounds are used more than any other material for the insulation of electrical conductors. They have the desirable characteristics of moisture-resisting qualities, ease of handling and termination, and extreme flexibility. On the other hand, they will not withstand such high temperatures or voltage without deterioration as will some of the other types of insulation. The different ingredients of the compound are combined by the process of vulcanization into a single homogeneous material.

A large number of different rubber compounds are available which have different characteristics, depending upon the service conditions for which they have been developed. It is feasible to include here only

those which are in most common use. For applications which require special characteristics the experts of the cable manufacturers should be consulted for advice with respect to the best available compound.

In general the character of the physical and electrical properties of the compound increase with the rubber content. However, rubber alone would not provide a suitable insulation. The proper choosing and proportioning of the other ingredients are important factors in obtaining the desired characteristics.

Code-grade rubber compound is the standard National Electrical Code rubber compound which complies with the minimum requirements for rubber insulation as specified by the Underwriters' Laboratories. It is designated as **Type R** insulation and represents the minimum standard of quality for a rubber insulation. It must meet certain requirements of the Underwriters' Laboratories with respect to elasticity, recovery from strain, tensile strength, and resistance to deterioration caused by age or temperature.

Heat-resisting rubber compounds have been developed which will withstand considerably higher temperatures than the Code-grade rubber compound. Such compounds meeting the Underwriters' Laboratories specifications are designated as **Type RH** insulation.

Moisture-resistant rubber compounds are available for installations where the wire will be subjected to wet conditions. These compounds are called moisture-resistant and submarine compounds. Those meeting the Underwriters' Laboratories specifications for interior wiring installation in wet locations are designated as **Type RW** insulation.

A very high grade compound consisting of 90 per cent unmilled grainless rubber is called **latex** rubber and is designated as **Type RU** and **Type RUW.** The **Type RUW** is moisture-resistant for installations in wet locations. Latex insulation is advantageous where it is desirable to limit the diameter of the wire to as small a value as possible.

Several other nonstandardized compounds, designated by the individual manufacturer's trade name, are available to meet special conditions of service, such as resistance to chemicals, ozone, and corona.

28. Thermoplastic Insulation.—Thermoplastic compounds have been developed for the insulation of electrical wires. Those meeting the specifications of the Underwriters' Laboratories are designated as **Type T, Type TW,** and **Type TA** insulation, respectively. The **Type T** insulation is satisfactory only for dry installations, whereas the **Type TW** is moisture-resistant and can be used in wet locations. **Type TA** is a combination of thermoplastic and asbestos insulation which is allowed to be used only for switchboard wiring. Thermoplastic compounds are designated by various trade names by the different manufacturers.

Thermoplastic insulation has the desirable characteristics of toughness and long life and is nonoxidizing, and comparable to rubber in dielectric strength. These qualities make it possible to reduce the thickness of the insulation employed as compared with rubber compounds and to omit any protective covering over the insulation.

29. Types and Characteristics of Wire and Cable Insulations

Insulation or covering type	N.E. Code designation	Max. permissible temperature, Deg. C. and F.	Relative characteristics			General field of application
			Flexibility	Moisture resistance	Dielectric strength	
Covered Wires						
1. Weatherproof	WP	80°C. (176°F.)	Fair	Poor	Very poor, is not really an insulation	Outdoor distribution and low-voltage transmission. Can be used for interior wiring only by special permission
2. Slow-burning	SB	90°C. (194°F.)	Fair	Poor		Exposed interior wiring on insulators in dry locations
3. Slow-burning weatherproof	SBW	90°C. (194°F.)	Fair	Poor		Exposed interior wiring on insulators in dry locations
Insulated Wires						
4. Rubber:						
a. Code compound	R	60°C. (140°F.)	Good	Good	Poor	General medium- and low-voltage use
b. Heat-resistant	RH	75°C. (167°F.)	Good	Good	Poor	General medium- and low-voltage use for temperature exceeding 60°C. or where its greater allowable carrying capacity will prove economical
c. Moisture-resistant	RW	60°C. (140°F.)	Good	Very good	Poor	Medium- and high-voltage use requiring high water resistance
d. Latex (regular)	RU	60°C. (140°F.)	Good	Good	Poor	General medium- and low-voltage use
e. Latex (moisture-resistant)	RUW	60°C. (140°F.)	Good	Good	Poor	General medium- and low-voltage use in wet locations
5. Thermoplastic compounds:						
a. Thermoplastic	T	60°C. (140°F.)	Fair	Good	Poor	General medium- and low-voltage use

thermoplastic						
c. Thermoplastic and asbestos	TA	90°C. (194°F.)	Fair	Good	Poor	General use and wet locations; open work
6. Varnished cambric:						
a. Standard black	.....	(75°C. − E^a)	Fair	Fair	Fair	Switchboard wiring only
b. Heat-resisting	V	85°C. (185°F.) allowed by N.E. Code. (90°C. − E^a) with max. of 85°C. (185°F.)	Fair	Fair	Fair	General medium-, low-, and high-voltage use
7. Paper:						General medium-, low-, and high-voltage use for temperature exceeding that allowed for standard black
a. Solid type	.....	(90°C. − E^a) with max. of 85°C.	Poor	Poor	Good	General high-voltage use
b. Oil-filled	.....	60°C. allowable for any voltage (90°C. − E^a) with max. of 85°C.	Poor	Poor	Excellent	General high and exceptionally high voltage use
c. Oilstatic	.....	60°C. allowable for any voltage	Poor	.....	Excellent	Exceptionally high voltage use
d. Untreated	.....	Same as 7*a* and 7*b*	....	.....	.....	Magnet wire
e. Treated	.....	90°C. (194°F.)	....	.....	.....	Magnet wire
8. Asbestos:		105°C. (221°F.)				
a. All-asbestos						
1. Nonimpregnated	A and AA	200°C. (392°F.)	Fair	Fair	Poor	Dry locations only, for low-voltage use at high temperature. In raceway only for leads to or within apparatus
2. Impregnated	AI and AIA	125°C. (257°F.)	Fair	Fair	Fair	Dry locations only, for low-voltage use at high temperature. In raceways only for leads to or within apparatus
b. Asbestos-varnished-cambric						
1. Outer asbestos braid	AVA	110°C. (230°F.)	Fair	Fair	Fair	Medium- and low-voltage use at medium temperatures in dry locations only
2. Lead covered	AVL	110°C. (230°F.)	Fair	Fair	Fair	Medium- and low-voltage use at medium temperatures in wet locations
3. Cotton braid covered	AVB	90°C. (194°F.)	Fair	Fair	Fair	Medium- and low-voltage use in dry locations only
9. Cotton	.....	90°C. (194°F.) for untreated; 105°C. (221°F.) for treated insulation	....	.....	.....	Magnet wire
10. Silk	.....					
11. Enamel	.....					
12. Fibrous glass	.....	.....	....	.....	.....	Magnet wire

E^a is phase-to-phase voltage of system in kilovolts.

30. Paper Insulation.—Impregnated-paper insulation provides the highest electrical breakdown strength, greatest reliability, and longest life of any of the materials employed for the electrical insulation of conductors. It will safely withstand higher operating temperatures than either rubber or varnished-cambric insulations. On the other hand it is not moisture resistant and must always be protected by a covering which will protect the insulation from moisture, such as a lead sheath. Paper-insulated cables are not so flexible and easy to handle as varnished-cambric or rubber-insulated cables and require greater care and time for the making of splices. Two methods are employed for insulating conductors with impregnated paper. Cables made by these methods are designated as either **solid type** or **oil-filled.**

The **solid-type** insulation is composed of layers of paper tapes applied helically over the conductor and impregnated with mineral oil (sometimes mixed with resin when so specified). The oil must be heavy enough to prevent bleeding when the cable is cut for splicing and terminations but at the same time must remain semifluid at the lowest operating temperatures. For cables installed as vertical risers, on steep grades, or under high operating temperatures, a heavier oil, designated as nonmigrating compound, is sometimes employed in order to prevent the migration of the oil from the high to the low points of the cable. The ordinary solid-type impregnated-paper insulation will give off inflammable and explosive gases when exposed to extremely high temperatures. It is common practice to clear cable failures on low-voltage network cables by leaving the power on and burning the fault clear. In order to reduce the possibility of damage to ducts and manhole structures from consequent explosions, special noninflammable, nonexplosive compounds are sometimes used for the impregnation of the paper insulation.

The paper of **oil-filled cable** is impregnated with a relatively thin liquid oil which is fluid at all operating temperatures. The cable is so constructed that channels are provided for longitudinal flow of the oil, and oil reservoirs are provided at suitable points in the cable installation. A positive pressure of moderate magnitude is thus maintained on the oil at all times, which prevents the formation of voids in the insulation due to changing temperature, stretching, or deformation of the lead sheath. When the cable is heated by load, the oil expands and flows lengthwise of the cable through the channels of the cable into the joints and out into the reservoirs. When the cable cools and the oil in the cable contracts, oil is forced back through the channels of the cable from the oil reservoirs. Any damage to the lead sheath will allow the entrance of moisture into a solid-type insulated cable. With oil-filled cable unless the damage is too severe, the positive internal oil pressure will prevent the entrance of moisture, so that, although there will be some loss of oil, operation can continue until it is convenient to make repairs.

The paper insulation of cables must be protected against moisture

This is usually accomplished by a tightly fitting lead sheath, which is extruded over the insulated cable during manufacture. In some special high-voltage installations called **Oilostatic Transmission Systems,** the lead sheath is used only temporarily for protection of the insulation during manufacture and shipment. In this system the insulated conductors, which are of the solid type, are contained in a buried metal pipe which is filled with oil maintained at a constant high pressure. The temporary lead sheath is stripped from the cable during installation.

A special grade of untreated paper is sometimes employed for insulating magnet wires. It is applied to the conductor in ribbon form as a helix with approximately one-third to one-half lap. This makes a low-cost insulation of constant thickness and slightly higher dielectric strength than that provided by cotton yarn, but it is less sturdy.

31. Varnished-cambric insulation has characteristics which are, in almost every respect, midway between those of rubber and paper. It is more flexible than paper but not so flexible as rubber except for large insulated cables. It is reasonably moisture resisting so that it does not always have to be covered with a lead sheath, but it cannot be operated without such protective covering if continuously immersed or if in continuously moist surroundings. With respect to dielectric strength, allowable temperature, and resistance to ionization and corona it is better than rubber but not so good as impregnated paper. Varnished cambric is not affected by ordinary oils and greases and will withstand hard service.

The term varnished cambric is misleading, since the cotton-fabric base of the insulation is not cambric. The correct designation should be varnished cloth, but because of long-established custom it is designated as varnished-cambric insulation. Varnished-cambric-insulated cable consists of conductors which are helically wrapped with cotton tape which has been previously filled and coated on both sides with insulating varnish. During the wrapping process a heavy nonhardening mineral compound is applied between the tapings to act as a lubricant when the cable is bent and, also, to fill up all spaces so as to prevent ionization and possible capillary absorption of moisture. Two types of varnished cloth are in common use for cable insulation, the **standard black finish,** and the **heat-resisting** type.

32. Asbestos provides a truly heat-resisting insulation which is suitable for use at temperatures beyond the limits allowable for other standard forms of cable insulation. However, it is only satisfactory for low-voltage installations (not more than 8,000 volts), since it cannot be applied to the conductors in a manner to give high dielectric strength characteristics to the cable insulation. Asbestos-insulated cables for power work are made in two types of construction: all asbestos or felted asbestos, and asbestos-varnished cambric.

All-asbestos or felted-asbestos insulated cable is made by covering

the conductor with a wall of felted-asbestos fibers. In some insulations the asbestos is saturated with flame- and heat-resisting compound, or flame-, heat-, and moisture-resisting compound.

Asbestos-varnished-cambric cable is insulated with a wall of impregnated asbestos combined with a wall of varnished cloth tapes applied in a series of helical wraps. The different standard types with the Underwriters designations are as follows:

Type A.—Nonimpregnated asbestos without an asbestos braid.

Type AA.—Nonimpregnated asbestos with outer asbestos braid.

Type AI.—Impregnated asbestos insulation without asbestos braid.

Type AIA.—Impregnated asbestos insulation with outer asbestos braid.

Type AVA.—Asbestos-varnished-cambric with outer asbestos braid.

Type AVL.—Asbestos-varnished-cambric insulation with an outer asbestos braid covered with a lead sheath.

Type AVB.—Asbestos-varnished-cambric insulation with outer flame-retardant cotton braid.

Asbestos coverings are used for magnet wire which must operate at high temperatures. It is bonded to the conductor by means of a coat of bonding insulating varnish. The asbestos covering is generally coated with insulating varnish or some compound in order to retard the penetration of moisture into the insulation and to increase the dielectric strength, thermal conductivity, and abrasion resistance.

33. Cotton yarn is often employed for the insulation of magnet wire. The wire is covered with one or more wraps of helically wrapped unbleached cotton yarn. When more than one wrap is employed, each wrap is applied in the reverse direction to that of the next inner wrap. The untreated cotton is neither heat resisting nor impervious to moisture. It is not fully considered to be an insulation, and coils wound with it should be treated or impregnated with an insulating compound by an approved process. The cotton yarn acts as a mechanical separator holding the conductors apart and providing a medium for the absorption and retention of the impregnating material. Cotton yarn is also used as a protective covering for enamel-insulated magnet wire.

34. Enamel is widely used as an insulation for magnet wire. It has excellent resistance to moisture, heat, and oil and possesses high dielectric strength. Enamel wire consists of a comparatively thin even coating of high-grade organic insulating enamel applied directly to the bare wire. It is made in two grades known as enameled and heavy enameled. The only difference in the two types is in the thickness of the enamel, the heavy enamel giving greater dielectric strength and abrasion resistance.

35. Silk yarn is employed in the same manner as cotton yarn (Sec. **33**) for the insulation of magnet wire. Silk coverings have better dielectric characteristics, give a neater appearance, and are mechanically stronger than cotton. Otherwise, all the statements in Sec. **33** respecting cotton-yarn insulations apply to silk.

Cellulose-acetate (**artificial silk**) tape or yarn is being used in many applications for the insulation of magnet wire as a substitute for or in combination with natural silk. Artificial silk has somewhat better electrical characteristics and gives a more uniform thickness of insulation. Its strength and abrasion resistance are not so good as those of natural silk.

36. Fibrous glass has been developed for the insulation of conductors. Up to the present time it has been employed only for the insulation of dynamo windings and magnet wire for classes of service requiring operation at high temperatures. The conductors are wound with one or more wraps of alkali-free fibrous-glass yarn.

37. Protective Coverings.—Most insulated conductors have the insulation protected from wear and deterioration due to surrounding conditions by some form of covering applied to the cable over the insulation. Protective coverings are also used on some noninsulated cables such as the weatherproof wire used for distribution purposes (see Covered Wires, Secs. **10** and **11**). The materials most commonly used for these protective coverings are listed in Sec. **38**. There is no one covering that will fulfill all the protective functions that are required for all classes of installations. Each one has its own particular advantages and limitations and consequently proper field of application. In many cases a combination of two or more of the different types of coverings is required in order to provide the necessary protection to the conductor and its insulation. In Tables 125 and 126 the different common types of coverings available are listed with the degree of protection that they will provide against the more common exposures encountered in service. The tables also give a guide to the general field of application of each type.

38. Protective Covering Materials and Finishes.

I. Nonmetallic.
  A. According to material of covering.
    1. Fibrous braids.
      a. Cotton.
        (1) Light.
        (2) Standard.
        (3) Heavy.
        (4) Glazed cotton.
      b. Seine twine or hawser cord.
      c. Hemp.
      d. Paper and cotton.
      e. Jute.
      f. Asbestos.
      g. Silk.
      h. Rayon.
      i. Fibrous glass.
    2. Tapes.
      a. Rubber-filled cloth tape.
      b. Combination of cotton cloth and rubber compounds.
    3. Woven covers (loom).
    4. Unspun felted cotton.
    5. Rubber jackets.
    6. Synthetic jackets.
    7. Jute and asphalt.
  B. According to saturant.
    1. Asphalt.
    2. Paint.

3. Varnish.

C. According to finish.
1. Stearin pitch and mica flake.
2. Paint.
3. Wax.
4. Lacquer.
5. Varnish.

II. Metallic.
A. Pure lead sheath.
B. Reinforced lead sheath.
C. Alloy-lead sheath.
D. Flat-band armor.
E. Interlocked armor.
F. Wire armor.
G. Basket-weave armor.

39. Fibrous braids are used extensively for protective coverings of cables. These braids are woven over the insulation of the cable so as to form a continuous covering without joints. The braid is generally saturated (Sec. **45**) with some compound in order to give resistance to some class of exposure such as moisture, flame, acid, etc. The outside braid is given one of the finishes described in Sec. **45** depending upon the application of the cable.

The most common braid is one woven from **light, standard,** or **heavy cotton yarn.** These coverings are designated, respectively, as I.P.C.E.A. Classes A, B, and C. I.P.C.E.A. are the initials of the Insulated Power Cable Engineers Association. The cotton can be furnished in a variety of colors for identification following an established color code in the industry.

Glazed cotton braid is composed of light cotton yarn treated with a sizing material before fabrication.

Seine-twine or **hawser-cord braid** is composed of cable-laid, hard-twisted cotton-yarn, braided to form a heavy durable covering which will withstand more rough usage than a braid made from common cotton yarn.

Hemp braid is woven from strong, durable, long-fibered hemp yarn which will withstand even rougher usage than seine-twine braid.

Paper and cotton braid is composed of paper twine interwoven with cotton threads.

Jute braid is woven from yarn composed of twisted jute fibers.

Asbestos braid is closely woven from long-fibered chrysotile asbestos yarn.

Silk and rayon braids are manufactured in the same manner as glazed cotton braid from real or artificial silk yarn.

Fibrous-glass braid is woven from fine, flexible glass threads and forms a covering resistant to flame, acids, alkalies, and oils.

40. Fibrous-tape coverings are frequently used as a part of the protective covering of cables. With tape coverings the material employed is fabricated into a tape before application to the cable, while with braid coverings the yarn is woven into a fabric during its application to the cable. In applying tape coverings the tape is wrapped helically around the cable, generally with a certain amount of overlapping of adjacent turns. The more common types of fibrous tapes employed in cable

manufacture are listed in Sec. **38.** Except for the duck tape, tape coverings are never used for the outer covering of a cable. They are employed for the covering directly over the insulation of individual conductors and for the inner covering over the assembled conductors of a multiconductor cable. They are frequently used under the sheath of a lead-sheathed cable. Duck tape made of heavy canvas webbing presaturated with asphalt compound is frequently used over a lead-sheathed cable for protection against corrosion and mechanical injury.

41. Woven covers commonly called **loom** are used for applications requiring exceptional abrasive-resisting qualities. These covers are composed of thick, heavy, long-fibered cotton yarn woven on the cable in a circular loom like that used for fire hose. (It is not a braid.) Although braid coverings are also woven they are not designated as such.

42. Unspun felted cotton is manufactured into a solid felted covering for cables for some special classes of service.

43. Several types of rubber and synthetic jacket coverings are available for the protection of insulated cable. There does not seem to be any standardization of these types of coverings. The different manufacturers have their own special compounds designated by their individual trade names. These compounds differ from the rubber compounds used for the insulation of cable in the fact that they have been perfected not for their insulating qualities but for resistance to abrasion, moisture, oil, gasoline, acids, earth solutions, alkalies, etc. Of course, no one jacket compound will provide protection against all the above exposures, as each one has its particular qualifications and limitations.

44. Jute and asphalt coverings are commonly used as a cushion between the cable insulation and a metallic armor. Frequently it is also employed as a corrosion-resisting covering over lead sheath or metallic armor. It consists of asphalt-impregnated jute yarn served helically around the cable or of alternate layers of asphalt-impregnated jute yarn serving and asphalt weatherproofing compound.

45. Saturants and Finishes for Fibrous Coverings.—Fibrous braids used for covering cables are thoroughly saturated and the outer surface is finished in order to provide protection against moisture, flame, weathering, or oil, etc. The common materials employed for saturating the braids are listed under *B* of Sec. **38,** and the common materials employed for finishing the outer surface under *C* of Sec. **38.** The more commonly employed combinations of saturants and finishes are listed in Table 127, together with the type of protection provided by each.

46. A pure lead sheath of uniform thickness tightly applied over the insulated cable by the extrusion process is practically the standard covering for cable for use in underground ducts and other wet locations. Where the cable will be exposed to special forms of corrosion, electrolytic action, or mechanical strain, one of the other coverings is used in combination with the lead sheath as a protective covering over the sheath.

47. A reinforced lead sheath is employed for mechanical strength when internal cable hydrostatic pressures exceed 15 lb. per sq. in. This construction consists of a double lead sheath. Around the inner sheath is wrapped a tape of hard-drawn copper, bronze, or other elastic metal, preferably nonmagnetic in character. This thin tape imparts considerable additional strength and elasticity to the sheath. However, it must be protected against wear and corrosion. For this reason a second lead sheath is applied over the tape. Such a finish is recommended for internal pressures up to 30 lb. per sq. in. It is commonly used on oil-filled cable near the bottom of severe grades or on solid cable at the base of vertical risers and at the bottom of extreme grades where pressure can accumulate.

48. An alloy-lead sheath is employed where additional mechanical strength and resistance to crystallization of the sheath are required. The most common alloy is one containing 2 per cent tin. Sometimes an antimony lead alloy is used. An alloy sheath is more resistant to gouging and abrasion during or after installation than a pure lead one.

49. Flat-band armor usually consists of two steel tapes applied on the outside of the cable in such a way that the openings between successive turns of the inner tape are covered by the outer tape. Usually these tapes are applied over a jute bedding introduced between them and the lead sheath or cable insulation; and they are frequently finished with an over-all layer of asphalted jute as a protection against corrosion. Ordinarily, plain steel tapes are recommended. Where corrosion conditions are apt to be severe, galvanized steel or nonferrous materials should be used.

50. Interlocked armor consists of a single strip of interlocking metal tape so applied over the insulation of the cable that the cable is always protected throughout its length. The interlocking construction prevents adjacent tapes from being squeezed together during installation or in service, with the consequent damage to the edges of the tapes, which sometimes occurs with flat-band steel armor; and, in addition, it eliminates gaps or open spaces as there is no break in the continuity of the interlocking strip. The shape of the armor is such that its physical strength against mechanical injury to the cable is superior to that of flat-band armor. The rounded surface of the armor tends to deflect blows from shovels or picks and also offers an additional buffer effect to blows that tend to pierce the armor, thereby minimizing damage to the lead sheath and insulation over which it is applied.

For rubber- or varnished-cambric-insulated cables used for interior work the armor is generally applied over a jute bedding which is introduced between the armor and the cable insulation.

For underground installation a lead sheath under the jute bedding of armor is required for paper cables, varnished-cambric cables, or 20 or 25 per cent Code-rubber cables.

An over-all asphalt-jute finish is sometimes used as an additional protection against corrosion, particularly if the cable is to be buried in the earth.

Galvanized steel is the standard material for armor employed in interior building wiring. For other power applications plain-steel armor is standard and suitable for most installations although galvanized armor will give a longer life. Nonmagnetic materials may be furnished for the larger single-conductor cables. Aluminum, copper, or bronze is frequently used where corrosion conditions are apt to be severe.

51. Wire armor consists of a layer of round metal wires wound helically and concentrically about the cable. The standard type employs galvanized-steel wires but, if desired, wire armor constructed of nonferrous materials may be obtained. Wire armor is recommended where extreme tensile strength and greatest mechanical protection are necessary. Galvanized-steel construction is stronger than nonferrous. Usually a layer of asphalt-treated jute is introduced between the armor and the sheath to prevent mechanical damage and to minimize electrolytic action. Galvanized armor may be used where corrosion would damage the iron, and further protection in the form of an over-all asphalt-jute finish is not uncommon.

52. Basket-weave armor is used where light weight and compactness are important. It consists of a braid of metal wire woven directly over the cable as an outer covering. Either galvanized-steel, bronze, copper, or aluminum wire is used for the braid, depending upon the service for which the cable is intended. This armor finish is used largely for shipboard wiring.

53. Classification of Cables according to Service.

1. General-purpose power cables (Sec. **54** and Tables 139 to 158).
2. Nonmetallic-sheathed building cable (Sec. **55** and Tables 139 and 159).
3. Armored building cable (Sec. **56** and Tables 139 and 160 to 162.
4. Annunciator and dampproof office wire (Sec. **57**).
5. Service cables (Sec. **58** and Table 139).
6. Aerial cables (Sec. **59** and Table 139).
7. Power cables for direct burial in earth (Sec. **60** and Table 139).
8. Network cables (Sec. **61**).
9. Series street-lightning cables (Sec. **62**).
10. Ornamental-pole and bracket wire (Sec. **63**).
11. Borehole or mine-shaft cable (Sec. **64** and Table 139).
12. Submarine cable (Sec. **65** and Table 139).
13. Control cable (Sec. **66** and Tables 139).
14. Electric-transportation-equipment cables (Sec. **67**).
15. Gas-tube-sign cables (Sec. **68**).
16. X-ray cable (Sec. **69**).
17. Portable power cables (Sec. **70** and Table 139).

18. Flexible cords and fixture wire (Secs. **71** and **72** and Tables 163 to 165).
19. Radio wires (Sec. **73**).
20. Automotive and aircraft wires and cables (Sec. **74**).
21. Telphone wires and cables (Sec. **75**).
22. Cable for shipboard use (Sec. **76**).
23. Magnet wire (Secs. **77** and **78** and Tables 166 to 172).

54. General-purpose power cables for underground ducts and interior wiring are available with rubber-, thermoplastic-, varnished-cambric-, paper-, or asbestos-insulated copper conductors. The particular type of any one of these insulations may be any of the types previously listed, depending upon the requirement of the service.

Class B stranding is the adopted standard for the conductors of these cables, but any one of the more flexible standard concentric or rope strandings is available. In addition, varnished-cambric- and paper-insulated cable may be obtained with the following construction:

Construction	Available for
Compack Round	Single conductor from No. 1 to 1,000,000. Multiconductor from No. 1 to 1,000,000. (Generally employed only for No. 1)
Compack Sector	Multiconductor No. 1/0 and larger
Annular Concentric	Single conductor, 750,000 to 5,000,000 cir. mils
Compack Segmental	Single conductor, 1,000,000 to 4,000,000 cir. mils
Hollow-core stranded	Single conductor, oil-filled paper cables, No. 2/0 to 2,000,000 cir. mils

General-purpose power cables are normally constructed in single- and three-conductor cables for all types of insulations mentioned. Rubber-insulated wires are also regularly made in two-conductor construction. Four-conductor cables are not standard construction but can be obtained.

The most common type of protective covering consists of a rubber-filled cloth tape and an outer cotton braid treated with moisture-resisting, flame-resisting, or moisture- and flame-resisting compounds. The tape is sometimes omitted. For applications where the cable will be subjected to rough usage the outer braid should be made of seine twine, hawser cord, or hemp. Where high flame resistance is required, asbestos braid should be used for the protective covering. For underground duct installation and interior wiring in wet locations, lead sheaths should be used. Where protection against corrosion, electrolysis, or damage due to accidental short-circuiting of open-circuited sheaths is required, the lead sheath is protected by an outer covering of duck tape, reinforced rubber, or jute and asphalt. For cable subjected to special exposures such as acids, alkalies, gasolines, etc., a suitable rubber or synthetic sheath should be employed (see Sec. **43**). Thermoplastic and latex-insulated wires do not require an outer protective covering.

The covered (not insulated) wires described in Sec. **10** would be included under the classification of general-purpose power cables.

General-purpose power cables with insulation and covering meeting the minimum requirements of the National Electrical Code are frequently called building wires and cables. The Code designation letters for these cables according to the type of insulation employed are given in Sec. **28** of this division and in Div. 8. In addition to these type letters, the Code also uses the following suffix letters:

1. No suffix letter indicates a single insulated conductor.
2. Suffix letter *D* indicates a twin wire with two insulated conductors laid parallel under an outer fibrous covering.
3. Suffix letter *M* indicates an assembly of two or more insulated conductors under a common outer fibrous covering.
4. Suffix letter *L* indicates an outer covering of lead.

If no number follows the designating letters of a cable, it indicates that the cable is for use at not more than 600 volts. Cables for use at higher voltages are so designated by adding the following numerical suffixes to the letter designations.

Numerical suffix	Maximum permissible voltage	Numerical suffix	Maximum permissible voltage
10	1,000	40	4,000
20	2,000	50	5,000
30	3,000		

The maximum voltages referred to in the table above are the operating voltages between phases of single- and two-phase systems, and three-phase systems with grounded or ungrounded neutral. For data on general-purpose power cables, refer to Tables 113 to 122 and 139 to 158.

55. Nonmetallic-sheathed building cable is employed for the economical exposed wiring of residences, farm buildings, small stores, etc. It consists of a two-, three-, or four-conductor, rubber or themoplastic-insulated cable, assembled as shown in Table 139. When desired a bare copper ground wire is incorporated in the cable assembly. The ground wire is laid in the interstices between the circuit conductors under the outer braid. Nonmetallic-sheathed cable is manufactured under several different trade names. The over-all dimensions will differ somewhat with different manufacturers (refer to Table 159).

56. Armored building cable consists of rubber- or themoplastic-insulated copper wire protected by a flexible galvanized-steel armor. It is manufactured with or without a lead sheath under the armor for protection against excessive dampness. The nonleaded type is regularly available in one-, two-, three-, and four-conductor assemblies in sizes

from No. 14 to No. 2, and also in size No. 1 for single conductor only. The leaded type is standard in two- and three-conductor assemblies in sizes from No. 14 to No. 6, and also in size No. 4 for three conductors only. The construction of these cables is shown in Table 139. The braid on the individual conductors is finished in different colors for identification of any conductor in installation. In installing these cables a short fiber bushing (see Sec. **8**) is inserted between the conductors and the steel armor wherever the cable is cut. For this reason the cables are frequently called armored bushed cables (**ABC**). The National Electrical Code designation is **AC** for the nonleaded type and **ACL** for the leaded type. They are also commonly called **BX** and **BXL,** respectively (refer to Tables 160 to 162).

Armored ground wire consists of a bare copper conductor with a flexible steel armor covering applied directly over the wire.

57. Annunciator or dampproof office wire is used for low-tension signaling circuits in residences and low-cost installations, Annunciator wire consists of a solid copper conductor covered with two servings of soft cotton saturated with paraffin. Dampproof office wire consists of a solid copper conductor covered with a weatherproof cotton wrap and an outer combination colored cotton braid.

58. Service Cables.—Special multiconductor cables have been developed to meet the requirements for connecting the pole line of the street distribution system with the service-entrance equipment on the consumer's premises. The following terminology derived from their application is used for service cables:

1. **Service-drop Cables.**—Overhead service conductors between pole and building.

2. **Service-entrance Cables.**—Service conductors which extend along the exterior and enter buildings to the meter, switch, or service equipment.

3. **Combination Service-drop and Service-entrance Cables.**—Service conductors continuing without break from the pole to the meter, switch, or service equipment.

4. **Underground Service-entrance Cables.**—Service conductors installed in conduit or directly in the earth and entering the building to the meter, switch, or service equipment.

Service cable is made in four different types designated by the Underwriters' Laboratories as follows:

1. **Type SD.**—Service-drop cable.
2. **Type SE.**—Service-entrance cable.
3. **Type ASE.**—Amored service-entrance cable.
4. **Type USE.**—Underground service-entrance cable.

Information on the application of the different types is given in Div. 9.

With the exception of Type USE, two general styles of service-cable construction are available, designated as nontamperproof and tamper-

proof. In the nontamperproof construction, which is the older style, all conductors are insulated. In the tamperproof style, all ungrounded conductors are insulated and the grounded conductor consists of a bare conductor concentrically wound over the insulated conductors. The tamperproof construction makes diversion of current difficult and practically impossible without leaving evidence.

Type USE service-entrance cable is similar in general construction to general power cables for direct burial in the earth.

Service cables are either rubber- or thermoplastic-insulated.

Service cables are available in two- and three-conductor assemblies.

Refer to Table 139 for data.

59. Aerial Cables.—Bare, weatherproof (weather-resisting) covered, and rubber-insulated tree wire are all used for overhead pole-line power circuits. Bare wire is used for most power-transmission circuits. See Sec. **15** and Table 82 for conductor materials employed and their field of application. Weatherproof (heat-resisting) covered wire is the general standard for distribution and low-voltage transmission circuits. Tree wire is used in distribution circuits where heavy tree growth would make the use of weatherproof wire unsuitable. Tree wire consists of a rubber-insulated copper wire protected with an abrasion-resisting covering. A.S.A. tree wire is made by different manufacturers according to specifications of the American Standards Association. The rubber insulation (performance compound) is covered with a layer of hard rubber or tough fiber tape and an outer braid of seine twine or hawser cord. The braid is treated with a special compound in order to render the wiring extremely tough and abrasion resisting. The outer surface is given a pitch and mica finish. Tree wire of better quality than the A.S.A. wire is also made by many manufacturers. One common type is a rubber compound or synthetic-rubberlike-compound-insulated wire covered with tough treated fiber tape and an outer closely woven, treated loom covering. A very high grade tree wire made by one manufacturer is known as Barkside. The construction consists of a conductor insulated with a special tree-wire synthetic compound, covered with a layer of presaturated Rohide fiber tape and an outer hawser-cord braid saturated with a special synthetic abrasion-resisting compound. The surface is given a pitch-and-mica finish.

The application of multiconductor aerial power cables is continually increasing. For messenger-type construction, general-purpose power cable with an alloy-lead sheath is commonly employed. In order to minimize weight of extremely large cables, it is generally advisable to eliminate the lead sheath. For such installations two types of cable construction have proved satisfactory. One type consists of either paper- or varnished-cambric-insulated cable supplied with a rubber hose jacket and an over-all band or interlocked armor of either steel or bronze. The other construction has utilized rubber- or varnished-cambric-insulated

shielded cable and an over-all seine twine or hawser braid saturated with a moisture-resisting compound. A layer of rubberized tape or presaturated duck tape is interposed between the over-all shielding band and the outer braid. The rubber insulation should be a corona-resisting compound except for the lower voltages.

A recent development is a self-supporting aerial cable which can be installed without the use of a supporting messenger cable. The standard construction employs a copper conductor insulated with either rubber or varnished cambric. If desired, moisture-resistant or corona-resistant rubber compounds may be used. Over the insulated conductors is placed a covering of alternate strands of round galvanized-steel wire interlocked with special copper or aluminum wires. Refer to Table 139 for illustrations and additional data.

60. Power cables for direct burial in the earth without ducts are available in both metallic and nonmetallic armored types. Cables of different manufacturers are fairly common in general construction but differ in details of assembly and manufacture.

The metallic types consist of a lead-sheathed general-purpose power cable protected with a jute and asphalt covering or a combination covering of a flat or interlocking tape armor together with jute and asphalt. Rubber is generally used for the insulation, but paper or varnished cambric may be employed if desired. They are available in one-, two-, and three-conductor assemblies. These metallic types are commonly called parkway cables.

The nonmetallic types consist of rubber-insulated conductors protected with some form of nonmetallic covering that will provide a moisture seal, resistance to corrosion, and sufficient mechanical strength. One type of armor assembly consists of a combination of layers of asbestos-base calk coatings, asbestos braid filled with asbestos-base calk, and treated fibrous tape, all enclosed in a presaturated heavy duck tape. The outer surface is finished with pitch and mica flake. A common armor assembly is the jute and asphalt covering described in Sec. **44.** Rubber and synthetic jackets are also employed for the protective covering of nonmetallic cables for direct burial in the earth. The jackets are frequently enclosed in a saturated duck tape, or sisal braid. All the nonmetallic types mentioned are available in one-, two-, and three-conductor assemblies. Some two-conductor cables are made with one central insulated conductor and one noninsulated conductor concentrically stranded over the insulation of the inner conductor. Refer to Table 139 for illustrations and additional data.

61. Network cables were developed primarily for underground duct installation for low-voltage secondary network service. They are single-conductor nonmetallic sheathed cables suitable for circuits operating at not more than 600 volts. These cables are insulated with a special rub-

ber compound covered with a layer of tape and an outer heavy cotton braid impregnated with a rot-resisting compound.

62. Series street-lighting cables differ from other power cables in the thickness of the insulation employed (see Table 124). They are rubber- or varnished-cambric-insulated single-conductor cables. Cables for this class of service are available in the following types:

Insulation	Type of covering	Max. open circuit voltage	Suitable for installation
Rubber	Lead sheath	8,000	In ducts
	Lead sheath covered with jute or duck tape	8,000	In earth
	Lead sheath with jute, steel tape, and jute over all	8,000	In earth
	Synthetic sheath covered with duck tape	6,000	In ducts
	Fibrous armor, calk, duck tape	3,000	In earth
	Semiconducting tape, drain wires, duck tape	10,000	In ducts
	Semiconducting tape, drain wires, fibrous armor, calk, duck tape	10,000	In earth
	Rubber sheath without shielding tape	6,000	In earth or ducts
	Rubber sheath with shielding tape	10,000	In earth or ducts
Varnished cambric	Lead sheath	14,500	In ducts
	Lead sheath covered with jute or duck tape	14,500	In earth
	Lead sheath with jute, steel tape, and jute over all	14,500	In earth

63. Ornamental-pole and bracket cable is a two-conductor, rubber-insulated cable specially designed for great flexibility and small over-all diameter. They are used for the interior wiring of ornamental lighting poles fed by underground cable and for the exterior wiring of pole-type bracket or mast-arm street-lighting fixtures. For voltages not exceeding 4,000, twin-type cable construction is employed, consisting of two rubber-insulated, single-cotton-braid-covered conductors laid parallel and enclosed in over-all tape and weatherproof braid. For voltages greater than 4,000, belted construction is employed. This assembly consists of two rubber-insulated and single-cotton-braid-covered conductors laid parallel and enclosed in a close-fitting belt of insulating compound. The belt insulation is covered with a tape and weatherproof braid.

64. Borehole or mine-shaft cables are specially designed to withstand the mechanical strains to which long lengths of vertically suspended cable are subjected. Both rubber and varnished cambric have been employed for the insulation of these cables. The rubber-insulated ones are made both with and without a lead sheath while the varnished-cambric cables are always lead sheathed. The cable is protected with a

steel-tape or steel-wire armor. Steel-tape armor should not be used unless supports can be provided at intervals not exceeding 50 ft. When the cable must be supported entirely from the top, wire armor must be used. The armor should be designed with sufficient strength to support the entire cable weight with a factor of safety of at least 5 and based on a tensile strength of 70,000 lb. per sq. in. The wire armor should be served with bands of steel wire in accordance with Table 136. Conductor-supported cables, instead of the above-described armor-supported ones, are sometimes used for this class of service. The rubber-insulated conductors are protected with a strong loom covering and installed in metallic borehole casings or conduit. Medium hard-drawn copper is used for the conductors, which entirely support the cable through conductor clamps and strain insulators.

Cables similar to the steel-armor borehole cables are employed for the vertical risers of tall buildings. For nonleaded construction a factor of safety of at least 7 should be used in designing the wire armor, while for leaded construction the minimum factor of safety should be 4.

Refer to Table 139 for illustration and additional data.

65. Submarine cables for installation under water in rivers, lakes, harbors, etc., are rubber-insulated power cables protected with a wire armor. The more common types of coverings employed are jute and wire armor; jute, wire armor, and jute; lead, jute, and wire armor; and lead, jute, wire armor, and jute. It is best to consider each submarine installation as a separate engineering problem and obtain the recommendations of the cable experts of reliable cable manufacturers. Refer to Table 139 for illustration and additional data.

66. Control cables consist of an assembly of several small conductors for carrying the relatively small currents for remote control of motors, circuit breakers, or other power equipment; for relay and metering circuits; for traffic-light control systems; etc. The standard assemblies vary from one conductor per cable to 37 conductors per cable. The size of the conductors ranges from No. 14 to No. 9. For most installations a 30 per cent rubber compound is used for the insulation of the conductors, although varnished cambric is also employed. For installations where the temperature is higher than normal, either a heat-resisting rubber compound or felted asbestos should be employed, the choice depending upon the temperature of the surroundings. Each individual conductor is covered with a color-coded cotton braid for protection of the insulation and identification of circuits. The conductors are assembled with jute fillers and bound together with a rubber-faced or asbestos binder tape.

For rubber-insulated cables the outer covering may be a standard cotton weatherproof braid with a black weatherproof wax finish; a lead sheath; a rubber jacket covered with a heavy cotton braid or duck tape; a metallic or nonmetallic armor for direct burial in the earth as described for power cable in Sec. **60** of this division; or a braid or jute bedding pro-

tected by interlocking steel-tape armor. With the rubber-jacket construction, the binder tape is eliminated. For asbestos-insulated cables the outer covering is an asbestos braid saturated with flame-, heat- and moisture-resisting compound. Refer to Table 139 for illustration and additional data.

67. Special cables for electric transportation equipment are manufactured in order to meet the particular requirements of this class of service with respect to flexibility and resistance to vibration. The conductors are rubber insulated. The cable covering usually consists of cotton braid or a rubber jacket.

68. Cables for gas-tube sign and oil-burner ignition systems should be of a type approved by the Underwriters' Laboratories for this service.

The Underwriters' designations for approved cables for this service are GTO-5, GTO-10, and GTO-15. In each case the numeral indicates the cable rating in kilovolts. Approved cables made by different manufacturers differ in details of construction. All employ a rubber compound for the insulation. A color-coded thread is run in the strands of the conductor as a voltage marking. A red thread indicates that the cable is satisfactory for 5,000 volts, yellow indicates 10,000 volts, and blue indicates 15,000 volts. The following coverings are available: glazed cotton with lacquer finish, weatherproof cotton braid with pitch and mica finish, cotton braid encased in lead sheath, and cotton braid encased in a basket-weave braid of tinned copper wires.

69. X-ray cables are designed to meet the special conditions encountered in the power-supply circuits to high-voltage X-ray tubes and similar equipment. As made by one manufacturer, they consist of a core made up of one or two rubber-insulated conductors for the cathode circuit. This core is enclosed in a flexible braid of tinned copper wires, which serves as the anode conductor. This braided conductor is insulated with a wall of synthetic compound covered with a special tape and a flexible closely woven shielding braid of tinned copper wires for the ground connection. In purchasing cable for this class of service the cable experts of the manufacturers should be consulted.

70. Portable power cables are designed for circuits supplying power to portable power equipment such as electric shovels, dredgers, air compressors, welders, etc. The individual conductors are generally insulated with a 40 per cent rubber compound. Cables of this type for voltages not exceeding 600 volts may be obtained with the following protective coverings: heavy cotton braid, seine-twine braid, loom sheath, rubber jacket, or jute and wire armor. These coverings are listed in the order of increasing resistance to wear. Only rubber jackets or jute-and-wire-armor coverings are employed for cables for voltages exceeding 600 volts. These high-voltage cables may be obtained in the following types:

Type	Covering	Ground wires	Shielding	Max. voltage recommended
W	Rubber jacket	Without	None	2,500
G	Rubber jacket	With	None	5,000
SH-A	Rubber jacket	Without	On each conductor	
SH-B*	Rubber jacket	Without	Over cabled conductor	
SH-C	Rubber jacket	With	Over cabled conductor	6,000
SH-D	Rubber jacket or jute and wire armor	With	On each conductor	
		No standard, consult manufacturers		

The conductors of portable power cables are made especially flexible by the use of Class G or H stranding (see Table 88), or, for special applications requiring even greater flexibility, special stranding may be employed. Single-conductor cables are regularly available in sizes from No. 8 to 700,000 cir. mils. Two-, three-, and four-conductor cables are standard in sizes from No. 8 to No. 4/0.

Refer to Table 139 for illustrations and additional data.

71. Fixture wire is used for the wiring of electric fixtures. There are 10 approved types: RF-64, RF-32, FF-64, FF-32, RUF, RUFF, TF, TFF, CF, and AF. Those wires with a single *F* in their designation may be solid or stranded. Those with *FF* must be made of wire with especially flexible stranding.

Types RF-64, RF-32, FF-64, and FF-32 are insulated with code rubber compound of a thickness of $\frac{1}{64}$ or $\frac{1}{32}$ in. as designated, and covered with a cotton or rayon braid.

Types RUF and RUFF are insulated with latex rubber of at least 18-mil thickness. The latex wires must be covered with a moisture-resistant, flame-retardant, nonmetallic covering.

Types TF and TFF are thermoplastic insulated with insulation of at least $\frac{1}{32}$-in. thickness and with no outer covering.

The operating temperature of all fixture wires except Types CF and AF must not exceed 60°C. (140°F.).

For the wiring of fixtures where the wire will be exposed to temperatures in excess of 140°F., the conductors must be protected by a heat-resisting insulation. There are two types of fixture wire suitable for these hot locations: Type AF and Type CF. **Type AF** wire is insulated with an asbestos covering which may or may not be protected by an outer braid of cotton or silk. This type of wire must be used for temperatures exceeding 194°F. (90°C.). **Type CF** wire is insulated with two braids of cotton or other thread impregnated and filled with a fire-resisting compound. This type of wire may be used for temperatures not exceeding 194°F. (90°C.). Fixtures with mogul sockets should always be considered as having their wires subjected to temperatures in excess of 194°F.

Types TF, TFF, AF, and CF must have insulation thickness of at least $\frac{2}{64}$ in.

Flexible cords of Types CFC, CFPO, CFPD, AFC, AFPO, and AFPD are multiconductor cords of CF and AF type of construction and may be employed for the wiring of fixtures. Rubber-covered flexible cords, are also used for the wiring of fixtures.

72. Flexible cord is the name applied to wires used for connecting portable appliances, small tools, or machinery to the receptacles of the wiring installation or for the wiring of the portable device itself. Flexible cords also are used in the wiring of pendant fixtures from the outlet box to the fixture. Table 163 lists the different types of approved flexible cords with their uses as allowed by the National Electrical Code rules.

73. Radio Wires.—Special types of wires have been developed to meet the special needs of the radio industry. They include antenna, lead-in, coil-lead, hookup, and transmission-line wires and microphone cable.

74. Automotive and aircraft wires and cables are specially designed to meet the special requirements of these two classes of service. They include high-tension ignition cables, primary wires for low-voltage service, and starter cables.

75. The telephone industry requires the use of special types of wires and cables. The multiconductor cables for main distribution circuits are dry-paper insulated, lead covered. A lead-antimony sheath is generally employed for aerial and underground installation in conduit or ducts. For direct burial in the earth and for some aerial work the lead sheath is protected with jute and steel-tape armor. Specially designed steel-wire-armored cables are used for submarine installation. It is common practice to terminate these paper-insulated cables by splicing to them a short length of textile-insulated lead-covered cable. A common type of this textile-insulated cable employs two layers of silk and one layer of cotton insulation on each conductor with the cable protected with a pure lead sheath. Rubber-insulated two-conductor cables protected with a weatherproof braid are used for service drops from pole to house. Hard-drawn copper, bronze, and copperweld conductors are used for these cables.

For circuits exposed to severe moisture and requiring from 2 to 12 conductors, rubber-insulated lead-covered cables are frequently used.

For interior wiring of individual telephone circuits, twisted-pair rubber-insulated cotton-braid-covered cables are employed. For exposed wiring the braid is glazed cotton, while, for conduit work, weatherproof braid is generally used.

76. Cables for shipboard use should be designed for the special requirements and severe service encountered in installations on board ship. Such cables are generally made in accordance with A.I.E.E. specifications, which are approved by the I.P.C.E.A. They are available in the follow-

ing standard types and also in special types to meet the customer's specifications.

1. Single-conductor rubber-insulated braid, with basket-weave armor in sizes No. 14 to 2,000,000 cir. mils.

2. Single-conductor, rubber- or varnished-cloth-insulated, rubber-hose jacket, with basket-weave armor in sizes No. 14 to 2,000,000 cir. mils.

3. Single-conductor, rubber- or varnished-cloth-insulated, leaded, with basket-weave armor in sizes No. 14 to 2,000,000 cir. mils.

4. Two- or three-conductor, with the same types of insulation and protection as for single conductors in size Nos. 14 to 2.

The basket-weave armor may be made of galvanized steel, aluminum alloy, copper, or bronze wire.

77. Magnet wire is the name applied to single-conductor insulated wires manufactured for the purpose of winding coils for electrical circuits. Round magnet wire is made of soft annealed solid copper wire in sizes from No. 46 to No. 4/0. Square- and rectangular-cross-section magnet wires are also available. The insulation employed is enamel, cotton, silk, cellulose acetate (artificial silk), paper, asbestos, synthetic resin, fibrous glass, or combinations of these materials. The different standard types of insulation employed are designated by the standardized symbols given in Table 166. All magnet wire made by a reliable manufacturer will meet certain specifications with respect to physical and electrical characteristics that have been standardized by the National Electrical Manufacturers' Association.

Enameled magnet wire consists of a bare copper wire insulated with a comparatively thin even coating of organic insulating enamel. The thickness of the enamel film varies with the diameter of the wire. Enameled magnet wire is made in two grades depending upon the thickness of enamel employed. The grade employing the thinner film is designated as **standard** or **plain enamel,** while the other grade, which has a thicker film of enamel, is called **heavy enamel** wire.

Cotton-covered magnet wire consists of one or more helical nonoverlapping wraps of unbleached cotton yarn applied over the conductor. Often it is advisable to use bonded cotton wire. Before applying the cotton yarn the conductor is coated with a high-grade insulating varnish in order to provide a bond between the conductor and the first layer of cotton. This bonding prevents the slipping of the cotton wrap during winding, prevents the unwrapping of the covering when wire is cut, and reduces the tendency of the insulation to open up in binding or in the crossing of turns. Untreated cotton is neither heat nor moisture resisting and is not considered to be a sufficient insulator. Coils wound with this type of magnet wire should therefore be impregnated with an insulating compound.

Silk-covered magnet wire is made in the same general way as cotton-covered wire, except that silk yarn is employed for the covering. As with cotton, it may or may not be bonded. Its use produces a neater and better-looking coil.

Artificial silk is sometimes employed for the covering of magnet wire. In some cases a cellulose-acetate yarn is applied in the same manner as real silk, while in others the conductor is helically wrapped with overlapping turns of cellulose-acetate tape. These cellulose-acetate coverings have better electrical characteristics than real silk but are not so strong mechanically.

Paper-insulated magnet wire consists of one or more layers of helically wrapped insulating paper with overlapping turns applied to the conductor. It may or may not be bonded.

Asbestos insulation is employed for magnet wire that must withstand high temperatures. The conductor is covered with a bonded layer of nonferrous asbestos. The outer surface may be finished in different ways to meet the requirements of the specific service.

Synthetic-resin-insulated magnet wire has recently been developed in order to overcome some of the deficiencies of the already existing types. It consists of a conductor coating of a combination of synthetic resins. This coating has much greater resistance to abrasion, continued heat, and film softening in solvents. At ordinary room temperatures its electrical characteristics are not quite so good as enameled wire, but on the other hand at higher temperatures they are somewhat better.

Fibrous-glass-covered magnet wire is a relatively new development. The wire is wrapped with one or more layers of fibrous-glass yarn. This type of wire will withstand especially high temperatures.

Refer to Tables 166 to 172 for data on magnet wire.

78. In the selection of the proper type of magnet wire for any application the following factors should be considered:

1. Utilization of winding space.
2. Resistance to abrasion.
3. Cost.
4. Insulating qualities.
5. Appearance.
6. Operating temperatures.

Tables 168 and 169 have been prepared giving general comparative values for the different types of magnet wire in order to serve as a general guide in the selection of magnet wire.

79. Method of Determining the Approximate Diameter of Any Cable.—When the approximate over-all diameter of a wire or cable not listed in the following tables is desired, it may be determined by means of one of the following formulas. Results obtained from these formulas will as a rule give minimum outside diameters. In order to allow for manufacturing tolerances, add 50 mils to the outside diameters as obtained from the formulas to obtain approximate maximum diameters.

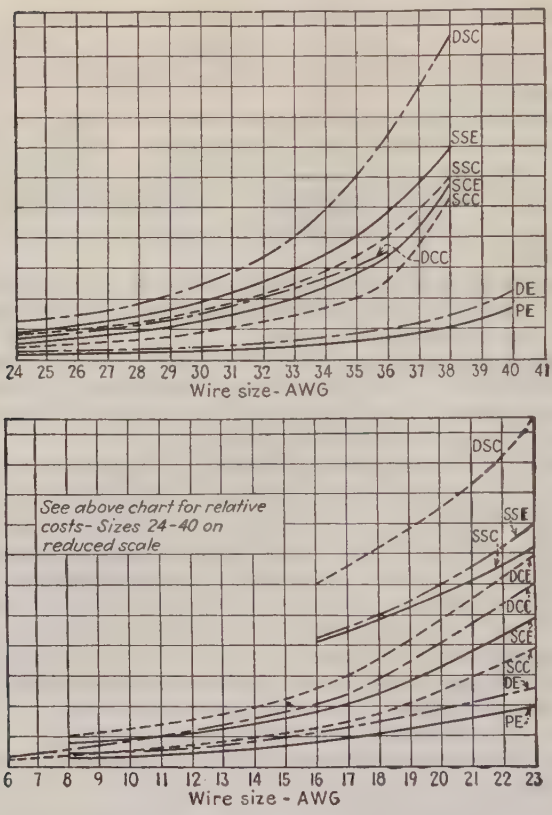


FIG. 5.—Relative costs of insulated magnet wires.

For single-conductor cables:

$$\text{O.D.} = d + 2T + 2t_c \tag{1}$$

For multiconductor nonshielded or belted cables:

$$\text{O.D.} = K(d + 2T + 2t_c) + 2t_o \tag{2}$$

For multiconductor belted cable:

$$\text{O.D.} = K(d + 2T) + 2t_B + 2t_o \tag{3}$$

For multiconductor shielded cable:

$$\text{O.D.} = K(d + 2T + 0.032) + 0.020 + 2t_o \tag{4}$$

where O.D. = outside diameter in inches; d = diameter of bare round conductor in inches; T = thickness of conductor insulation in inches; t_c = thickness of covering over insulation of individual conductors in inches; t_B = thickness of belt insulation in inches; t_o = thickness of over-all protective covering in inches; and K = value from following table:

Conductor	Value of K
Two conductor, round	2.00
Two conductor, flat, max. diam	2.00
Two conductor, flat, min. diam	1.00
Three conductor, round	2.16
Three conductor, ordinary sector	1.95
Three conductor, compack sector	1.90
Four conductor, round	2.41
Four conductor, ordinary sector	2.20
Four conductor, compack sector	2.15

Procedure in applying above formulas:

1. Determine manner of assembly of cable. (Table 139 gives information on standard types.)

2. Determine diameters d of bare round conductors of type employed from Tables 83 to 95. For all sector cables take value of d equal to diameter of concentric stranded round conductor of equivalent size.

3. Determine thickness of conductor insulation T from Tables 115 to 122.

4. If any covering is used over insulation of individual conductors, determine thickness t_c from Table 128.

5. If cable is belted, determine thickness of belt insulation t_B from Table 116 or 122.

6. Determine thickness of over-all protective covering t_o from Tables 128 to 134, 137 or 138.

Example.—Determine outside diameter of a three-conductor, concentric-stranded, No. 4/0, varnished-cambric, belted lead-sheathed, 2,200-volt cable.

From reference to Cable 10 of Table 139 it is determined that for such a cable no covering would be used over the insulation of the individual conductors and that the over-all covering would consist of simply the lead sheath applied directly over the belt insulation. The outside diameter will be found from the formula O.D. $= 2.16(d + 2T) + 2t_B + 2t_o$, since t_c will equal zero. From Table 83 it is found that Class B stranding would be employed. From Table 86 the diameter of a Class B No. 4/0 concentric-stranded conductor is 0.528 in. From Table 122 the thickness of insulation for 3,000 volts is 0.094 in. for each conductor and 0.031 in. for the belt insulation. The diameter of the cable core under the lead sheath is therefore:

$$2.16[0.528 + (2 \times 0.094)] + (2 \times 0.031) = (2.16 \times 0.716) + 2 \times 0.031 = 1.609 \text{ in.}$$

From Table 129 the thickness of the lead sheath should be 0.109 in. The over-all diameter of the cable is $1.609 + (2 \times 0.109) = 1.827$ inches. This result checks very closely with the data of Table 148, which gives 1.820 as the diameter for such a cable.

80. Comparison of Wire and Sheet-metal Gage Diameters or Thicknesses in Inches

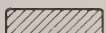
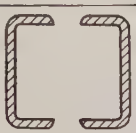
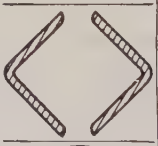
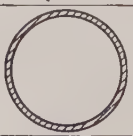
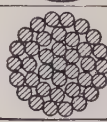
Gage No.	(1) American wire gage (A.w.g.)[a]	(2) Steel wire gage	(3) Birmingham iron wire gage (Stubs)	(4) Stubs steel wire gage	(5) (British) standard wire gage	(6) Steel music wire gage	(7) U. S. standard	(8) American zinc	(9) Birmingham
15/0	.....	.....	.....	.....	.....	.....	.....	.....	1.0000
14/0	.....	.....	.....	.....	.....	.....	.....	.....	0.9583
13/0	.....	.....	.....	.....	.....	.....	.....	.....	0.9167
12/0	.....	.....	.....	.....	.....	.....	.....	.....	0.8750
11/0	.....	.....	.....	.....	.....	.....	.....	.....	0.8333
10/0	.....	.....	.....	.....	.....	.....	.....	.....	0.7917
9/0	.....	.....	.....	.....	.....	.....	.....	.....	0.7500
8/0	.....	.....	.....	.....	.....	.....	.....	.....	0.7083
7/0	.....	0.4900	.....	.....	0.5000	.....	0.5000	.....	0.6666
6/0	.....	0.4615	.....	.....	0.4640	.....	0.4687	.....	0.6250
5/0	.....	0.4305	.....	.....	0.4320	.....	0.4375	.....	0.5883
4/0	0.4600	0.3938	0.454	.....	0.4000	.....	0.4062	.....	0.5416
3/0	0.4100	0.3625	0.425	.....	0.3720	.....	0.3750	.....	0.5000
2/0	0.3650	0.3310	0.380	.....	0.3480	0.0087	0.3437	.....	0.4452
1/0	0.3250	0.3065	0.340	.....	0.3240	0.0093	0.3125	.....	0.3964
1	0.2890	0.2830	0.300	0.227	0.3000	0.0098	0.2812	0.002	0.3532
2	0.2580	0.2625	0.284	0.219	0.2760	0.0106	0.2656	0.004	0.3147
3	0.2290	0.2437	0.259	0.212	0.2520	0.0114	0.2500	0.006	0.2804
4	0.2040	0.2253	0.238	0.207	0.2320	0.0122	0.2344	0.008	0.2500
5	0.1820	0.2070	0.220	0.204	0.2120	0.0138	0.2187	0.010	0.2225
6	0.1620	0.1920	0.203	0.201	0.1920	0.0157	0.2035	0.012	0.1981
7	0.1440	0.1770	0.180	0.199	0.1760	0.0177	0.1875	0.014	0.1764
8	0.1280	0.1620	0.165	0.197	0.1600	0.0197	0.1719	0.016	0.1570
9	0.1140	0.1483	0.148	0.194	0.1440	0.0216	0.1562	0.018	0.1398
10	0.1020	0.1350	0.134	0.191	0.1280	0.0236	0.1406	0.020	0.1250
11	0.0910	0.1205	0.120	0.188	0.1160	0.0260	0.1250	0.024	0.1113
12	0.0810	0.1055	0.109	0.185	0.1040	0.0283	0.1094	0.028	0.0991
13	0.0720	0.0915	0.095	0.182	0.0920	0.0305	0.0937	0.032	0.0882
14	0.0640	0.0800	0.083	0.180	0.0800	0.0323	0.0821	0.036	0.0785
15	0.0570	0.0720	0.072	0.178	0.0720	0.0342	0.0703	0.040	0.0699
16	0.0510	0.0625	0.065	0.175	0.0640	0.0362	0.0625	0.045	0.0625
17	0.0450	0.0540	0.058	0.172	0.0560	0.0382	0.0562	0.050	0.0556
18	0.0400	0.0475	0.049	0.168	0.0480	0.0400	0.0500	0.055	0.0495
19	0.0360	0.0410	0.042	0.164	0.0400	0.0420	0.0437	0.060	0.0440
20	0.0320	0.0348	0.035	0.161	0.0360	0.0440	0.0375	0.070	0.0392

Comparison of Wire and Sheet-metal Gage Diameters or Thicknesses in Inches (*Continued*)

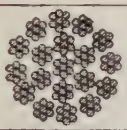
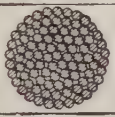
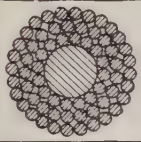
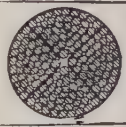
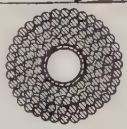
Gage No.	(1) American wire gage (A.w.g.)[a]	(2) Steel wire gage	(3) Birmingham iron wire gage (Stubs)	(4) Stubs steel wire gage	(5) (British) standard wire gage	(6) Steel music wire gage	(7) U. S. standard	(8) American zinc	(9) Birmingham
21	0.0285	0.0317	0.032	0.157	0.0320	0.0460	0.0344	0.080	0.0349
22	0.0253	0.0286	0.028	0.155	0.0280	0.0480	0.0312	0.090	0.0312
23	0.0226	0.0258	0.025	0.153	0.0240	0.0510	0.0281	0.100	0.0278
24	0.0210	0.0230	0.022	0.151	0.0220	0.0550	0.0250	0.125	0.0247
25	0.0179	0.0204	0.020	0.148	0.0200	0.0590	0.0219	0.250	0.0220
26	0.0159	0.0181	0.018	0.146	0.0180	0.0630	0.0187	0.375	0.0196
27	0.0142	0.0173	0.016	0.143	0.0164	0.0670	0.0172	0.500	0.0175
28	0.0126	0.0162	0.014	0.139	0.0148	0.0710	0.0156	1.000	0.0156
29	0.0113	0.0150	0.013	0.134	0.0136	0.0740	0.0141	.....	0.0139
30	0.0100	0.0140	0.012	0.127	0.0124	0.0780	0.0125	.....	0.0123
31	0.0089	0.0132	0.010	0.120	0.0116	0.0820	0.0109	.....	0.0110
32	0.0080	0.0128	0.009	0.115	0.0108	0.0860	0.0101	.....	0.0098
33	0.0071	0.0118	0.008	0.112	0.0100	.....	0.0094	.....	0.0087
34	0.0063	0.0104	0.007	0.110	0.0092	.....	0.0086	.....	0.0077
35	0.0056	0.0095	0.005	0.108	0.0084	.....	0.0078	.....	0.0069
36	0.0050	0.0090	0.004	0.106	0.0076	.....	0.0070	.....	0.0061
37	0.0045	0.0085	.....	0.103	0.0068	.....	0.0066	.....	0.0054
38	0.0040	0.0080	.....	0.101	0.0060	.....	0.0062	.....	0.0048
39	0.0035	0.0075	.....	0.099	0.0052	.....	.....	.....	0.0043
40	0.0031	0.0070	.....	0.097	0.0048	.....	.....	.....	0.0039
41	.....	0.0066	.....	0.095	0.0044	.....	.....	.....	0.0034
42	.....	0.0062	.....	0.092	0.0040	.....	.....	.....	0.0031
43	.....	0.0060	.....	0.088	0.0036	.....	.....	.....	0.0027
44	.....	0.0058	.....	0.085	0.0032	.....	.....	.....	0.0024
45	.....	0.0055	.....	0.081	0.0028	.....	.....	.....	0.00215
46	.....	0.0052	.....	0.079	0.0024	.....	.....	.....	0.0019
47	.....	0.0050	.....	0.077	0.0020	.....	.....	.....	0.0017
48	.....	0.0048	.....	0.075	0.0016	.....	.....	.....	0.0015
49	.....	0.0046	.....	0.072	0.0012	.....	.....	.....	0.00135
50	.....	0.0044	.....	0.069	0.0010	.....	.....	.....	0.0012
51	.....	.....	.....	.....	.....	.....	.....	.....	0.0011
52	.....	.....	.....	.....	.....	.....	.....	.....	0.00095

[a] The American wire gage sizes have been rounded off to about the usual limits of commercial accuracy.

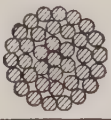
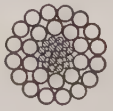
81. Make-ups of Electrical Conductors

Type	Illustration	Application
	Copper	
Solid, round.....		Bare wire in sizes Nos. 4/0 to 45. Covered, non-insulated in sizes Nos. 4/0 to 14. Insulated in sizes Nos. 6 to 14 for power work. Insulated in sizes Nos. 1/0 to 46 for magnet wire
Solid, grooved.....		Trolley contact wire sizes 350,000 cir. mils to No. 1/0
Solid, figure eight..		Trolley contact wire sizes 350,000 cir. mils to No. 1/0
Solid, figure nine...		Trolley contact wire size 400,000 cir. mils
Solid, square.....		Magnet wire and windings for electrical equipment
Solid, rectangular..		Magnet wire, windings for electrical equipment, bus bars
Solid, channels....		Bus bars
Solid, angle.....		Bus bars
Solid, tubes.....		Bus bars
Standard, concentric-stranded....		Bare, covered, and insulated in sizes 5,000,000 cir. mils to No. 20

Make-ups of Electrical Conductors (*Continued*)

Type	Illustration	Application
Standard, rope stranded.....		Rubber-sheathed cords and cables in sizes 5,000,000 cir. mils to No. 8
Bunched stranded.		Flexible cords and fixture wire in sizes Nos. 10 to 22
Annular concentric-stranded with rope core.		Varnished-cambric-insulated and solid-type paper-insulated single-conductor cables in sizes 5,000,000 to 750,000 cir. mils
Compack-stranded, round.		Varnished-cambric-insulated and solid-type paper-insulated cables in sizes 1,000,000 cir. mils to No. 1 single conductor and size No. 1 for multiconductor
Compack-stranded, sector.		Multiconductor paper-insulated cables both solid and oil-filled types in sizes 1,000,000 cir. mils to No. 1/0
Compack-stranded, segmental.		Varnished-cambric-insulated and solid-type paper-insulated single-conductor cables in sizes 4,000,000 to 1,000,000 cir. mils
Hollow-core, stranded.		Oil-filled paper-insulated single-conductor cables in sizes 2,000,000 cir. mils to No. 2/0
Tubular-segmental, Type HH.....		High-voltage long-distance transmission
Iron or Steel		
Solid, round.....		Bare in sizes Nos. 4, 6, and 8 for power work. Bare in sizes Nos. 4 to 14 for telephone and telegraph work

Make-ups of Electrical Conductors (*Continued*)

Type	Illustration	Application
Three-strand.....		Bare in sizes Nos. 4, 6, and 8
Copperweld		
Solid, round.....		Bare in sizes Nos. 4/0 to 12. Weatherproof covered in sizes Nos. 2 to 12. Rubber-insulated, single conductors in size Nos. 4/0 to 12 and two conductors in sizes Nos. 14 and 17
Concentric-stranded		Bare or rubber covered, single conductor in diameters from 0.910 to 0.174 in.
Copperweld and Copper		
Stranded.....		Bare in various combinations of strands in cable sizes from 586,800 cir. mils to No. 8.—Weatherproof covered in sizes Nos. 2 to 8
Copper and Steel		
Three-strand.....		Bare in sizes Nos. 2 to 12
All Aluminum		
Stranded.....		Bare or weatherproof covered in sizes 1,590,000 cir. mils to No. 4
Aluminum and Steel (A.C.S.R.)		
Annular aluminum, stranded with steel core.		Bare in sizes 1,590,000 cir. mils to No. 4 Weatherproof covered in sizes Nos. 4/0 to 8
Bronze		
Solid, round.....		Bare or weatherproof covered in sizes Nos. 4 to 14

82. Application Guide for Electrical Conductor Materials

Application			Suitable conductor material: Copper, soft drawn	Copper, medium hard drawn	Copper, hard drawn	Copperweld	Copperweld and copper	Copper and steel-stranded	All aluminum	Aluminum and steel A.C.S.R.	Steel or iron	Bronze
Bare transmission and distribution wires...	Heavy and medium loads	Short and medium spans	..	√	√	..	..	..	√	√		
		Long spans	..	..	√	..	√	..	..	√		
	Light loads	Short and medium spans	..	√	√	..	..	..	√	√		
		Long spans	..	..	√	√	..	√	..	√	√	
Covered non-insulated transmission and distribution wires..	Heavy loads	Short and medium spans	√	√	..	..	..	..	√			
		Long spans	..	√	..	..	..	..	..	√		
	Light loads	Short and medium spans	√	√	..	..	..	..	√			
		Long spans	..	..	√	√	√	..	..	√	..	√
Insulated cables			√									
Telephone and telegraph lines, ground wires			..	..	√	√	..	..	..	..	√	
Signal circuits			..	..	√	√						
Trolley contact wires			..	..	√	..	..	..	..	..	..	√
Trolley feeders			..	√								

83. Factors for Determining Diameter of Concentric-stranded Copper Cables[a]

Number of strands	3	7	12	19	37	61	91	127 and over
Factor	1.244	1.134	1.199	1.147	1.151	1.152	1.153	1.154

[a] To determine approximate diameter of bare concentric-stranded copper cables, multiply diameter of solid wire of same cross-sectional area by the proper factor from above table.

84. Solid Bare Copper Conductors

(Anaconda Wire and Cable Co.)

Size, A.w.g.	Wire diam., in.	Cross-sectional area		Weight		Hard-drawn wire		Medium hard-drawn wire		Soft or annealed wire	
		Cir. mils	Sq. in.	Per 1,000 ft. lb.	Per mile, lb.	Min. breaking strength, lb.[a]	Max. resistance per 1,000 ft. at 20°C., ohms[b]	Min. breaking strength, lb.[a]	Max. resistance per 1,000 ft. at 20°C., ohms[b]	Max. breaking strength, lb.[a]	Max. resistance per 1,000 ft. at 20°C., ohms[b]
4/0	0.4600	211,600	0.1662	640.5	3,382	8,143	0.05045	6,980	0.05019	5,983	0.04993
3/0	0.4096	167,800	0.1318	507.9	2.682	6,722	0.06361	5,667	0.06329	4,745	0.06296
2/0	0.3648	133,100	0.1045	402.8	2,127	5,519	0.08021	4,599	0.07980	3,763	0.07939
1/0	0.3249	105,500	0.08289	319.5	1,687	4,517	0.1011	3,730	0.1006	2,984	0.1001
1	0.2893	83,690	0.06573	253.3	1,338	3,688	0.1287	3,024	0.1282	2,432	0.1262
2	0.2576	66,370	0.05213	200.9	1,061	3,003	0.1625	2,450	0.1617	1,929	0.1592
3	0.2294	52,630	0.04134	159.3	841.2	2,439	0.2049	1,984	0.2038	1,530	0.2007
4	0.2043	41,740	0.03278	126.4	667.1	1,970	0.2584	1,584	0.2570	1,213	0.2531
5	0.1819	33,100	0.02600	100.2	529.1	1,591	0.3258	1,264	0.3241	961.9	0.3192
6	0.1620	26,250	0.02062	79.46	419.6	1,280	0.4108	1,010	0.4087	762.9	0.4025
7	0.1443	20,820	0.01635	63.02	332.7	1,030	0.5181	806.6	0.5154	605.0	0.5075
8	0.1285	16,510	0.01297	49.97	263 9	826.0	0.6533	643.9	0 6499	479.8	0.6400
9	0.1144	13,090	0.01028	39.63	209.3	661.2	0.8238	514.2	0 8195	380.5	0.8070
10	0.1019	10,380	0.008155	31.43	165.9	529.2	1.039	410.4	1.033	314.0	1.018
11	0.09074	8,234	0.006467	24.92	131.6	422.9	1 310	327.6	1.303	249.0	1.283
12	0.08081	6,530	0.005129	19.77	104.4	337.0	1 652	261.6	1.643	197.5	1.618
13	0.07196	5,178	0.004067	15.68	82.77	268.0	2.083	208.8	2.072	156.6	2 040
14	0.06408	4,107	0.003225	12.43	65.64	213.5	2.626	166.6	2.613	124.2	2.573
15	0.05707	3,257	0.002558	9.858	52.05	169.8	3.312	133.0	3.295	98.48	3.244
16	0.05082	2,583	0.002028	7.818	41.28	135.1	4.176	106.2	4.154	78.10	4.091
17	0.04526	2,048	0.001609	6.200	32.74	107.5	5.266	84.71	5.239	61.93	5.158
18	0.04030	1,624	0.001276	4.917	25.96	85.47	6.640	67.61	6.606	49.12	6.505
19	0.03589	1,288	0.001012	3.899	20.59	67.99	8.373	53.95	8 330	38.95	8.202
20	0.03196	1,022	0.0008023	3.092	16 33	54.08	10.56	43 05	10 50	30.89	10.34

21	0.02846	810.1	0.0006363	2.452	12.95	43.07	13.31	34.36	13.24	24.50	13.04
22	0.02535	642.5	0.0005046	1.945	10.27	34.26	16.79	27.41	16.70	19.43	16.45
23	0.02257	509.5	0.0004001	1.542	8.143	27.25	21.17	21.87	21.06	15.41	20 74
24	0.02010	404.0	0.0003173	1.223	6.458	21.67	26.69	17.45	26.56	12.69	26.15
25	0.01790	320.4	0.0002517	0.9699	5.121	17.26	33.66	13.92	33.49	10.07	32.97
26	0.01594	254.1	0.0001996	0.7692	4.061	13.73	42.44	11.11	42 23	7.983	41 58
27	0.01420	201.5	0.0001533	0.6100	3.221	10.92	53 52	8.863	53.25	6.331	52 43
28	0.01264	159.8	0.0001255	0.4837	2.554	8.698	67.49	7.070	67 14	5.021	66 11
29	0.01126	126.7	0.00009954	0.3836	2.026	6.918	85.10	5.640	84.66	3.981	83 37
30	0.01003	100.5	0.00007894	0.3042	1.606	5.502	107.3	4.499	106.8	3.157	105.1
31	0.008928	79.70	0.00006260	0.2413	1.274	4.376	135.3	3.589	134.6	2.504	132.6
32	0.007950	63.21	0.00004964	0.1913	1.010	3.485	170.6	2.862	169.8	1.986	167.2
33	0.007080	50.13	0.00003937	0.1517	0.8011	2.772	215.2	2.283	214.1	1.575	210.8
34	0.006305	39.75	0.00003122	0.1203	0.6353	2.204	271.3	1.821	269.9	1.249	265.8
35	0.005615	31.52	0.00002476	0.09542	0.5038	1.755	342.1	1.452	340.4	0.9904	335.2
36	0.005000	25.00	0.00001963	0.07567	0.3996	1.396	431.4	1.158	429.2	0.7854	422.6
37	0.004453	19.83	0.00001557	0.06001	0.3169	1.110	544.0	0.9238	541.2	0.6228	532.9
38	0.003965	15.72	0.00001235	0.04759	0.2513	0.8829	686.0	0.7367	682.4	0.4939	672.0
39	0.003531	12.47	0.000009793	0.03774	0.1993	0.7031	865.0	0.5876	860.5	0.3917	847.4
40	0.003145	9.888	0.000007766	0.02993	0.1580	0.5592	1,091	0.4685	1,085	0.3106	1,069
41	0.002800	7.842	0.000006159	0.02374	0.1253	0.4434	1,375	0.3716	1,368	0.2464	1,347
42	0.002494	6.219	0.000004884	0.01882	0.09939	0.3517	1,734	0.2947	1,725	0.1954	1,699
43	0.002221	4.932	0.000003873	0.01493	0.07882	0 2789	2,187	0 2337	2,176	0.1549	2,142
44	0.001978	3.911	0.000003072	0.01184	0.06251	0.2212	2,758	0.1853	2,743	0.1229	2,702
1 Mil	0.001000	1.000	0.000000785	0.003027	0.01598	0.05655	10,790	0.04738	10,730	0.03142	10,570

[a] The breaking strengths are based on A.S.T.M. specification requirements, using minimum values for hard and medium hard-drawn wire, and maximum values for soft wire.

[b] The resistance values in this table are trade maximums and are higher than the average values for commercial wire. The following values for the conductivity of copper were used:

A.S.T.M. Requirements

	Conductivity, I.A.C.S. % at 20°C.	Resistivity, lb. per mile-ohm at 20°C.
Hard-drawn, 0.325 in. and larger	97.16	900.77
Hard-drawn, 0.324 in. and smaller	96.16	910.15
Medium hard-drawn, 0.325 in. and larger	97.66	896.15
Medium hard-drawn, 0.324 in. and smaller	96.66	905.44
Soft or annealed	98.16	891.58

85. Stranded Bare Copper Conductors
(Anaconda Wire and Cable Co.)

Size				Weight[b]		Hard-drawn, min. breaking strength, lb.[c]	Medium hard-drawn, min. breaking strength, lb.[c]	Soft-drawn, max. breaking strength, lb.[c]
Cir. mils	A.w.g.	Stranding, class[a]	Cable diam., in.	Per 1,000 ft., lb.	Per mile, lb.			
5,000,000	.....	B	2.581	15,890	83,910	219,500	173,200	145,300
5,000,000	.....	A	2.580	15,890	83,910	216,300	171,800	145,300
4,500,000	.....	B	2.448	14,300	75,520	200,400	156,900	130,800
4,500,000	.....	A	2.448	14,300	75,520	197,200	154,600	130,800
4,000,000	.....	B	2.309	12,590	66,490	178,100	139,500	116,200
4,000,000	.....	A	2.307	12,590	66,490	175,600	138,500	116,200
3,500,000	.....	B	2.159	11,020	58,180	155,900	122,000	101,700
3,500,000	.....	A	2.158	11,020	58,180	153,400	120,200	101,700
3,000,000	.....	B	1.998	9,353	49,390	134,400	104,600	87,180
3,000,000	.....	A	1.998	9,353	49,390	131,700	103,900	87,180
2,500,000	.....	B	1.824	7,794	41,150	111,300	87,170	72,650
2,500,000	.....	A	1.823	7,794	41,150	109,600	85,880	72,650
2,000,000	.....	B	1.632	6,175	32,600	90,050	70,210	58,120
2,000,000	.....	A	1.630	6,175	32,600	87,790	69,270	58,120
1,750,000	.....	B	1.526	5,403	28,530	78,800	61,430	50,850
1,750,000	.....	A	1.526	5,403	28,530	77,930	61,020	50,850
1,500,000	.....	B	1.412	4,631	24,450	67,540	52,650	43,590
1,500,000	.....	A	1.411	4,631	24,450	65,840	51,950	43,590
1,250,000	.....	B	1.289	3,859	20,380	56,280	43,880	36,320
1,250,000	.....	A	1.288	3,859	20,380	55,670	43,590	36,320
1,000,000	.....	B, A	1.152	3,088	16,300	45,030	35,100	29,060
1,000,000	.....	AA	1.151	3,088	16,300	43,830	34,350	29,060
900,000	.....	B, A	1.094	2,779	14,670	40,520	31,590	26,150
900,000	.....	AA	1.092	2,779	14,670	39,510	31,170	26,150
800,000	.....	B, A	1.031	2,470	13,040	36,360	28,270	23,250
800,000	.....	AA	1.029	2,470	13,040	35,120	27,710	23,250
750,000	.....	B, A	0.998	2,316	12,230	34,090	26,510	21,790
750,000	.....	AA	0.997	2,316	12,230	33,400	26,150	21,790
700,000	.....	B, A	0.964	2,161	11,410	31,820	24,740	20,340
700,000	.....	AA	0.963	2,161	11,410	31,170	24,410	20,340
600,000	.....	B	0.893	1,853	9,781	27,530	21,350	18,140
600,000	.....	A, AA	0.891	1,853	9,781	27,020	21,060	17,440
500,000	.....	B, A	0.813	1,544	8,151	22,510	17,550	14,530
500,000	.....	AA	0.811	1,544	8,151	21,950	17,320	14,530
450,000	.....	B, A	0.772	1,389	7,336	20,450	15,900	13,080
450,000	.....	AA	0.770	1,389	7,336	19,750	15,590	13,080
400,000	.....	B	0.728	1,235	6,521	18,320	14,140	11,620
400,000	.....	A, AA	0.726	1,235	6,521	17,560	13,850	11,620
350,000	.....	B	0.681	1,081	5,706	16,060	12,450	10,580
350,000	.....	A	0.679	1,081	5,706	15,590	12,200	10,170
350,000	.....	AA	0.710	1,081	5,706	15,140	12,020	10,170
300,000	.....	B	0.630	926.3	4,891	13,870	10,740	9,071
300,000	.....	A	0.629	926.3	4,891	13,510	10,530	8,718
300,000	.....	AA	0.657	926.3	4,891	13,170	10,390	8,718
250,000	.....	B	0.575	771.9	4,076	11,560	8,952	7,559

Stranded Bare Copper Conductors *(Continued)*

Size				Weight[b]		Hard-drawn, min. breaking strength, lb.[c]	Medium hard-drawn, min. breaking strength, lb.[c]	Soft-drawn, max. breaking strength, lb.[c]
Cir. mils	A.w.g.	Stranding, class[a]	Cable diam., in.	Per 1,000 ft., lb.	Per mile, lb.			
250,000	....	A	0.574	771.9	4,076	11,360	8,836	7,265
250,000	.....	AA	0.600	771.9	4,076	11,130	8,717	7,265
211,600	4/0	B	0.528	653.3	3,450	9,617	7,479	6,149
211,600	4/0	A, AA	0.552	653.3	3,450	9,453	7,378	6,149
211,600	4/0	A, AA[d]	0.522	653.3	3,450	9,154	7,269	6,149
167,800	3/0	B	0.470	518.1	2,736	7,698	5,970	5,074
167,800	3/0	A, AA	0.492	518.1	2,736	7,556	5,890	4,876
167,800	3/0	A, AA[d]	0.464	518.1	2,736	7,366	5,812	4,876
133,100	2/0	B	0.419	410.9	2,170	6,153	4,766	4,025
133,100	2/0	.....	0.437	410.9	2,170	6,049	4,704	3,868
133,100	2/0	A, AA	0.414	410.9	2,170	5,927	4,641	3,868
105,500	1/0	B	0.373	325.7	1,720	4,899	3,803	3,190
105,500	1/0	.....	0.390	325.7	1,720	4,840	3,753	3,190
105,500	1/0	A, AA	0.368	325.7	1,720	4,750	3,703	3,066
83,690	1	B	0.332	258.4	1,364	3,898	3,037	2,531
83,690	1	A	0.328	258.4	1,364	3,804	2,958	2,432
83,690	1	AA	0.360	255.9	1,351	3,620	2,875	2,432
66,370	2	B, A	0.292	204.9	1,082	3,045	2,361	2,007
66,370	2	AA	0.320	202.9	1,071	2,913	2,299	1,929
52,630	3	B, A	0.260	162.5	858.0	2,433	1,885	1,591
52,630	3	AA	0.285	160.9	849.6	2,359	1,835	1,529
41,740	4	B, A	0.232	128.9	680.5	1,938	1,505	1,262
41,740	4	AA	0.254	127.6	673.8	1,879	1,465	1,213
33,100	5	B	0.206	102.2	539.6	1,542	1,201	1,001
26,250	6	B	0.184	81.05	427.9	1,228	958.6	793.7
20,820	7	B	0.164	64.28	339.4	977.2	765.3	629.6
16,510	8	B	0.146	50.98	269.1	777.2	610.7	499.2
13,090	9	B	0.130	40.42	213.4	618.1	487.3	395.8
10,380	10	B	0.116	32.05	169.2	491.6	388.9	313.9
6,530	12	B	0.0915	20.16	106.5	311.1	247.7	197.5
4,107	14	B	0.0726	12.68	66.95	197.1	157.7	124.2
2,583	16	B	0.0576	7.975	42.11	124 7	100.4	81.15
1,624	18	B	0.0456	5.014	26.47	78 98	63.89	51.02
1,022	20	B	0.0363	3.155	16.66	50.06	40.69	32.11

[a] Class of stranding in accordance with A.S.T.M. Specification B 8-35T.

[b] Weight increased 2 per cent to allow for cabling, except as follows:

Cir. Mils	Per Cent
5,000,000 and 4,500,000	5
4,000,000 and 3,500,000	4
3,000,000 and 2,500,000	3

[c] The breaking strengths are based on A.S.T.M. specification requirements, using minimum values for hard- and medium hard-drawn cable, and maximum values for soft cable.

[d] Optional construction, see Table 86.

86. Stranding Data for Copper Conductors—Concentric Stranded, A.S.A. Standards

Size		Class AA			Class A			Class B		
A.w.g.	Cir. mils	Number of strands	Diam. of individual strands, mils	Approx. over-all diam., in.	Number of strands	Diam. of individual strands, mils	Approx. over-all diam., in.	Number of strands	Diam. of individual strands, mils	Approx. over-all diam., in.
	5,000,000	...	.....	.....	169	172.0	2.580	217	151.8	2.581
	4,500,000	...	.....	.....	169	163.2	2.448	217	144.0	2.448
	4,000,000	...	.....	.....	169	153.8	2.307	217	135.8	2.309
	3,500,000	...	.....	.....	127	166.0	2.158	169	143.8	2.159
	3,000,000	...	.....	.....	127	153.7	1.998	169	133.2	1.998
	2,500,000	...	.....	.....	91	165.7	1.823	127	140.3	1.824
	2,000,000	...	.....	.....	91	148.2	1.630	127	125.5	1.631
	1,900,000	...	.....	.....	91	144.5	.....	127	122.3	
	1,800,000	...	.....	.....	91	140.6	.....	127	119.1	
	1,750,000	...	.....	.....	91	138.7	1.526	127	117.4	1.526
	1,700,000	...	.....	.....	91	136.7	.....	127	115.7	
	1,600,000	...	.....	.....	91	132.6	.....	127	112.2	
	1,500,000	...	.....	.....	61	156.8	1.411	91	128.4	1.412
	1,400,000	...	.....	.....	61	151.5	.....	91	124.0	
	1,300,000	...	.....	.....	61	146.0	.....	91	119.5	
	1,250,000	...	.....	.....	61	143.1	1.288	91	117.2	1.289
	1,200,000	...	.....	.....	61	140.3	.....	91	114.8	
	1,100,000	...	.....	.....	61	134.3	.....	91	109.9	
	1,000,000	37	164.4	1.151	61	128.0	1.152	61	128.0	1.152
	900,000	37	156.0	1.092	61	121.5	1.094	61	121.5	1.094
	800,000	37	147.0	1.029	61	114.5	1.031	61	114.5	1.031
	750,000	37	142.4	0.997	61	110.9	0.998	61	110.9	0.998
	700,000	37	137.5	0.963	61	107.1	0.964	61	107.1	0.964
	650,000	37	132.5	.....	61	103.2	.....	61	103.2	
	600,000	37	127.3	0.891	37	127.3	0.891	61[c]	99.2	0.893
	550,000	37	121.9	.....	37	121.9	.....	61[d]	95.0	
	500,000	19	162.2	0.811	37	116.2	0.814	37	116.2	0.814
	450,000	19	153.9	0.770	37	110.3	0.772	37	110.3	0.772
	400,000	19	145.1	0.726	19	145.1	0.726	37	104.0	0.728
	350,000	12	170.7	0.710	19	135.7	0.679	37	97.3	0.681
	300,000	12	158.1	0.657	19	125.7	0.629	37	90.0	0.630
	250,000	12	144.3	0.600	19	114.7	0.574	37	82.2	0.575
4/0	211,600	7[a]	173.9	0.522	7[a]	173.9	0.522	19	105.5	0.528
3/0	167,800	7[b]	154.8	0.464	7[b]	154.8	0.464	19	94.0	0.470
2/0	133,100	7	137.9	0.414	7	137.9	0.414	19	83.7	0.418
1/0	105,500	7	122.8	0.368	7	122.8	0.368	19	74.5	0.373
1	83,690	3	167.0	0.360	7	109.3	0.328	19	66.4	0.332
2	66,370	3	148.7	0.320	7	97.4	0.292	7	97.4	0.292
3	52,630	3	132.5	0.285	7	86.7	0.260	7	86.7	0.260
4	41,740	3	118.0	0.254	7	77.2	0.232	7	77.2	0.232
5	33,100	...	.....	.....	....	.....	.....	7	68.8	0.206
6	26,250	...	.....	.....	....	.....	.....	7	61.2	0.184
7	20,820	...	.....	.....	....	.....	.....	7	54.5	0.164
8	16,510	...	.....	.....	....	.....	.....	7	48.6	0.146
9	13,090	...	.....	.....	....	.....	.....	7	43.2	0.130
10	10,380	...	.....	.....	....	.....	.....	7	38.5	0.116
12	6,530	...	.....	.....	....	.....	.....	7	30.5	0.0915
14	4,107	...	.....	.....	....	.....	.....	7	24.2	0.0726
16	2,583	...	.....	.....	....	.....	.....	7	19.2	0.0576
18	1,624	...	.....	.....	....	.....	.....	7	15.2	0.0456
20	1,022	...	.....	.....	....	.....	.....	7	12.1	0.0363

[a] Optional construction for No. 4/0 A.w.g. size in Class AA and Class A is 12 wires of 132.8 mils diameter.

[b] Optional construction for No. 3/0 A.w.g. size in Class AA and Class A is 12 wires of 118.3 mils diameter.

[c] Optional construction for 600,000 C.M. size in Class B is 37 wires of 127.3 mils diameter.

[d] Optional construction for 550,000 C.M. size in Class B is 37 wires of 121.9 mils diameter.

The above data are approximate and subject to normal manufacturing tolerances.

87. Stranding Data for Copper Conductors—Concentric Stranded, A.S.A. Standards (*Continued*)

Size		Class C			Class D		
A.w.g.	Cir. mils	Number of strands	Diam. of individual strands, mils	Approx. over-all diam., in.	Number of strands	Diam. of individual strands, mils	Approx. over-all diam., in.
	5,000,000	271	135.8	2.580	271	135.8	2.580
	4,500,000	271	128.9	2.448	271	128.9	2.448
	4,000,000	271	121.5	2.307	271	121.5	2.307
	3,500,000	217	127.0	2.158	271	113.6	2.158
	3,000,000	217	117.6	1.998	271	105.2	1.998
	2,500,000	169	121.6	1.824	217	107.3	1.824
	2,000,000	169	108.8	1.631	217	96.0	1.631
	1,900,000	169	106.0	.....	217	93.6	
	1,800,000	169	103.2	.....	217	91.1	
	1,750,000	169	101.8	1.526	217	89.8	1.526
	1,700,000	169	100.3	.....	217	88.5	
	1,600,000	169	97.3	.....	217	85.9	
	1,500,000	127	108.7	1.414	169	94.2	1.414
	1,400,000	127	105.0	.....	169	91.0	
	1,300,000	127	101.2	.....	169	87.7	
	1,250,000	127	99.2	1.290	169	86.0	1.290
	1,200,000	127	97.2	.....	169	84.3	
	1,100,000	127	93.1	.....	169	80.7	
	1,000,000	91	104.8	1.153	127	88.7	1.154
	900,000	91	99.4	1.095	127	84.2	1.096
	800,000	91	93.8	1.032	127	79.4	1.032
	750,000	91	90.8	0.999	127	76.8	1.000
	700,000	91	87.7	0.965	127	74.2	0.966
	650,000	91	84.5	.....	127	71.5	
	600,000	91	81.2	0.893	127	68.7	0.894
	550,000	91	77.7	.....	127	65.8	
	500,000	61	90.5	0.815	91	74.1	0.817
	450,000	61	85.9	0.773	91	70.3	0.774
	400,000	61	81.0	0.730	91	66.3	0.731
	350,000	61	75.7	0.683	91	62.0	0.684
	300,000	61	70.1	0.632	91	57.4	0.633
	250,000	61	64.0	0.577	91	52.4	0.578
4/0	211,600	37	75.6	0.529	61	58.9	0.530
3/0	167,800	37	67.3	0.471	61	52.4	0.471
2/0	133,100	37	60.0	0.419	61	46.7	0.419
1/0	105,500	37	53.4	0.376	61	41.6	0.376
1	83,690	37	47.6	0.333	61	37.0	0.333
2	66,370	19	59.1	0.295	37	42.4	0.296
3	52,630	19	52.6	0.261	37	37.7	0.262
4	41,740	19	46.9	0.230	37	33.6	0.231
5	33,100	19	41.7	0.209	37	29.9	0.210
6	26,250	19	37.2	0.186	37	26.6	0.186
7	20,820	19	33.1	0.166	37	23.7	0.166
8	16,510	19	29.5	0.147	37	21.1	0.148
9	13,090	19	26.2	0.131	37	18.8	0.132
10	10,380	19	23.4	0.107	37	16.7	0.117
12	6,530	19	18.5	0.093	37	13.3	0.093
14	4,107	19	14.7	0.074	37	10.5	0.074
16	2,583	19	11.7	0.058			
18	1,624	19	9.2	0.046			
20	1,022	19	7.3	0.037			

The above data are approximate and subject to normal manufacturing tolerances.

88. Stranding Data for Copper Conductors—Rope Stranded; I.P.C.E.A. Standards

Size, cir. mils or A.w.g.	Stranding data								Approx. over-all diam., in.	Weight per 1,000 ft., net lb.
	Flexible stranding (Class G)				Extra-flexible stranding (Class H)					
	Total number of strands	Diam. of individual strands, mils	Number of ropes	Number of strands each rope	Total number of strands	Diam. of individual strands, mils	Number of ropes	Number of strands each rope		
5,000,000	1,159	65.7	61	19	1,729	53.8	91	19	2.959	16,200
4,500,000	1,159	62.3	61	19	1,729	51.0	91	19	2.805	14,600
4,000,000	1,159	58.7	61	19	1,729	48.1	91	19	2.646	13,000
3,500,000	1,159	55.0	61	19	1,729	45.0	91	19	2.475	11,400
3,000,000	1,159	50.9	61	19	1,729	41.7	91	19	2.294	9,470
2,500,000	703	59.6	37	19	1,159	46.4	61	19	2.088	8,090
2,000,000	703	53.3	37	19	1,159	41.5	61	19	1.868	6,470
1,900,000	703	52.0	37	19	1,159	40.5	61	19	1.823	6,160
1,800,000	703	50.6	37	19	1,159	39.4	61	19	1.773	5,830
1,750,000	703	49.9	37	19	1,159	38.9	61	19	1.751	5,680
1,700,000	703	49.2	37	19	1,159	38.3	61	19	1.724	5,510
1,600,000	703	47.7	37	19	1,159	37.2	61	19	1.674	5,200
1,500,000	427	59.3	61	7	703	46.2	37	19	1.617	4,860
1,400,000	427	57.3	61	7	703	44.6	37	19	1.561	4,530
1,300,000	427	55.2	61	7	703	43.0	37	19	1.505	4,210
1,250,000	427	54.1	61	7	703	42.2	37	19	1.477	4,060
1,200,000	427	53.0	61	7	703	41.3	37	19	1.446	3,890
1,100,000	427	50.8	61	7	703	39.6	37	19	1.386	3,570
1,000,000	427	48.4	61	7	703	37.7	37	19	1.320	3,240
900,000	427	45.9	61	7	703	35.8	37	19	1.253	2,920
800,000	427	43.3	61	7	703	33.7	37	19	1.180	2,590
750,000	427	41.9	61	7	703	32.7	37	19	1.145	2,440
700,000	427	40.5	61	7	703	31.6	37	19	1.106	2,270
650,000	427	39.0	61	7	703	30.4	37	19	1.064	2,110
600,000	427	37.5	61	7	703	29.2	37	19	1.022	1,940
550,000	427	35.9	61	7	703	28.0	37	19	0.980	1,790
500,000	259	43.9	37	7	427	34.2	61	7	0.923	1,610
450,000	259	41.7	37	7	427	32.5	61	7	0.878	1,460
400,000	259	39.3	37	7	427	30.6	61	7	0.826	1,290
350,000	259	36.8	37	7	427	28.6	61	7	0.773	1,130
300,000	259	34.0	37	7	427	26.5	61	7	0.716	969
250,000	259	31.1	37	7	427	24.2	61	7	0.653	808
4/0	133	39.9	19	7	259	28.6	37	7	0.602	686
3/0	133	35.5	19	7	259	25.5	37	7	0.536	540
2/0	133	31.6	19	7	259	22.7	37	7	0.477	428
1/0	133	28.2	19	7	259	20.2	37	7	0.424	339
1	133	25.1	19	7	259	18.0	37	7	0.378	269
2	49	36.8	7	7	133	22.3	19	7	0.336	213
3	49	32.8	7	7	133	19.9	19	7	0.299	168
4	49	29.2	7	7	133	17.7	19	7	0.266	133
5	49	26.0	7	7	133	15.8	19	7	0.237	106
6	49	23.1	7	7	133	14.0	19	7	0.210	83
8	49	18.4	7	7	133	11.1	19	7	0.167	52

See notes at top of page 147.

A.w.g. sizes for individual strands are permissible, provided their area is not more than 2 per cent below required area. Sizes Nos. 2, 3 0, and 4 0 A.w.g. can be supplied in alternate combinations as follows:

Wire size	No. 2 A.w.g.	No. 3/0 A.w.g.	No. 4/0 A.w.g.
Total number of strands	259	427	427
Diameter individual strands (mils)	16.0	19.8	22.3
Number of ropes	37	61	61
Number of strands each rope	7	7	7

Flexible stranded conductors Nos. 10 to 22 A.w.g. are normally supplied in bunched-stranded form; refer to Tables 90 and 91.

Conforms to all requirements of I.P.C.E.A. Project 46.

The above data are approximate and subject to normal manufacturing tolerances.

89. Stranding Data for Copper Conductors—Bunched-stranded Ropes; I.P.C.E.A. Standards

Nominal size, cir. mils or A.w.g.	Class J: Min. number of No. 30 A.w.g. strands	Class L: Min. number No. 34 A.w.g. strands	Approx. o.d., in.	Nominal size, A.w.g.	Class J: Min. number of No. 30 A.w.g. strands	Class L: Min. number No. 34 A.w.g. strands	Approx. o.d., in.
1,000,000	9,951	.....	1.52	1	836	2,109	0.44
900,000	8,956	.....	1.43	2	661	1,672	0.39
800,000	7,961	.....	1.35	3	524	1,326	0.36
750,000	7,463	.....	1.31	4	410	1,052	0.31
700,000	6,966	.....	1.28	5	330	832	0.27
650,000	6,468	.....	1.25	6	262	661	0.22
600,000	5,971	.....	1.21	7	208	524	0.20
550,000	5,473	.....	1.17	8	165	416	0.17
500,000	4,976	12,579	1.08	9	131	330	0.16
450,000	4,478	11,321	1.00	10	104	262	0.12
400,000	2,981	10,063	0.96	12	65	165	0.10
350,000	3,483	8,806	0.90	14	41	104	0.08
300,000	2,986	7,557	0.82	16	26	65	0.06
250,000	2,488	6,297	0.78	18	16	41	0.05
4/0	2,106	5,330	0.73	20	10	26	0.04
3/0	1,670	4,227	0.61				
2/0	1,325	3,353	0.55				
1/0	1,050	2,658	0.49				

90. Stranding Data for Copper Conductors, Bunched Stranded—I.P.C.E.A. Special Strandings

Nominal size, A.w.g.	Class P: Fixture wire, commercial		Class Q: 10,000-cycle heater cord		Class R: Special fixture wire, portable cords, etc.		Class S: Type S cord		Class T: Oscillating fan cord	
	Number strands	Size strand, A.w.g.	Number strands	Size strand, A.w.g.	Number strands	Size strand, A.w.g.	Number strands	Size strand, A.w.g.	Number strands	Size strand, A.w.g.
10	65	28	...	..	165	32	104	30		
12	41	28	...	..	104	32	84	31		
14	26	28	...	..	65	32	84	33		
16	16	28	104	36	41	32	65	34		
18	10	28	65	36	26	32	41	34	165	40
20	7	28	41	36	16	32	26	34	104	40

91. Recommended Stranding Practice for Copper Conductors

Type of Stranding	Recommended Uses
Class AA	For bare cable
Class A	For weather-resistant (weatherproof), slow-burning, and slow-burning weather-resistant cables, and for bare cable where greater flexibility than is afforded by Class AA is required
Class B	For cable insulated with various materials such as rubber, paper, varnished cloth, etc., and for the cables indicated under Class A where greater flexibility is required
Class C and Class D	For cable where greater flexibility is required than is provided by Class B cable
Class G	For all rubber-sheathed cords and cables for normal use
Class H	For all rubber-sheathed cords and cables where extreme flexibility is required, such as for use on take-up reels, over sheaves, etc.
Class J	For use in fixture wire, portable cords, etc
Class L	For use in welding cable, heater cord, Type SJ cord
Class P	For commercial fixture wire
Class Q	For 10,000-cycle heater cord
Class R	For special fixture wire, portable cords, etc.
Class S	For Type S cord
Class T	For oscillating fan cord
Bunched stranded	For extremely flexible conductors of sizes from No. 10 to No. 22

92. Annular, Concentric-stranded, Rope-core Conductors—I.P.C.E.A. Standard

(General Cable Corp.)

Nominal size, cir. mils	Actual area, cir. mils	Approx. rope core size, in.	Number of strands	Diam. individual strands, in.	Max. over-all diam., in.	Weight per 1,000 ft.	
						Copper only, net lb.	Copper and core, net lb.
750,000	741,735	0.375	54	0.1172	1.108	2,312	2,362
800,000	800,865	0.468	65	0.1110	1.164	2,497	2,575
900,000	906,565	0.500	66	0.1172	1.234	2,826	2,905
1,000,000	1,023,766	0.563	65	0.1255	1.346	3,192	3,304
1,250,000	1,260,020	0.750	80	0.1255	1.533	3,928	4,127
1,500,000	1,512,024	1.000	96	0.1255	1.783	4,714	5,068
1,750,000	1,753,083	1.125	107	0.1280	1.923	5,466	5,914
2,000,000	1,978,387	1.3125	120	0.1284	2.114	6,168	6,778
2,500,000	2,488,320	1.500	120	0.1440	2.394	7,758	8,555
3,000,000	3,044,304	1.625	116	0.1620	2.627	9,492	10,427
3,500,000	3,595,428	2.000	137	0.1620	3.007	11,319	12,735
4,000,000	4,015,332	2.250	153	0.1620	3.262	12,641	14,433
4,500,000	4,408,992	2.500	168	0.1620	3.517	14,013	16,226
5,000,000	4,960,116	2.875	189	0.1620	3.897	15,765	18,691

The following tolerances are included in over-all diameters:

Nominal Size, M Cir. Mils	Tolerance, In.
750–3,000	0.030
3,001–3,500	0.035
3,501–4,000	0.040
4,001–4,500	0.045
4,501–5,000	0.050

The following allowances for stranding are included in the metallic weight:

Nominal Size, M Cir. Mils	Tolerance, Per Cent
750–3,000	3
3,001–4,000	4
4,001–5,000	5

93. Compack-stranded Conductors—Segmental

(General Cable Corp.)

Size, cir. mils	Number of strands	Approx. over-all diam., in.	Size, cir. mils	Number of strands	Approx. over-all diam., in
1,000,000	148	1.152	2,500,000	244	1.825
1,250,000	148	1.288	3,000,000	364	2.000
1,500,000	148	1.412	3,500,000	364	2.159
1,750,000	244	1.526	4,000,000	364	2.308
2,000,000	244	1.631			

94. Compack-stranded Conductors—Round and Sector

(General Cable Corp.)

Size A.w.g. or cir. mils	Round		120-degree sector		90-degree sector	
	Number of strands	Over-all diam., in.	V-gage depth,[a] in.	Number of strands	V-gage depth,[a] in.	Number of strands
1	19	0.299				
1/0	19	0.336	0.288	19	0.340	19
2/0	19	0.376	0.323	19	0.382	19
3/0	19	0.423	0.364	37		
4/0	19	0.475	0.417 (*L*) 0.410 (*H*)	37 37	0.482	37
250,000	37	0.520	0.455 (*L*) 0.447 (*H*)	37 37	0.525	37
300,000	37	0.570	0.497 (*L*) 0.490 (*H*)	37 37	0.572	37
350,000	37	0.616	0.539 (*L*) 0.532 (*H*)	37 37	0.620	37
400,000	37	0.659	0.572 (*L*) 0.566 (*H*)	37 37		
500,000	37	0.736	0.642 (*L*) 0.635 (*H*)	61 61	0.740	61
600,000	61	0.813	0.700 (*L*) 0.690 (*H*)	61 61		
700,000	61	0.877	0.754 (*L*) 0.742 (*H*)	91 91		
750,000	61	0.908	0.780 (*L*) 0.767 (*H*)	91 91		
800,000	61	0.938	0.795[b]	91		
1,000,000	61	1.060	0.900[b]	91		

The above data are approximate and subject to normal manufacturing tolerances.

L and *H* indicate V-gage depths of the bare conductor for "light" walls (up to and including 13/64 in.) and "heavy" walls (14/64 in. and over), respectively. The shape of the sector and, therefore, the V-gage depth in the larger sizes depend on whether a light or heavy wall of insulation is to be applied.

[a] V-gage depth is the distance from the center point of the exterior arc of the bare sector to the point where the lines of the sides of the conductor if prolonged would intersect. For rough calculation purposes, V-gage depth in inches can be taken as 90 per cent of the square root of the nominal area of the conductor expressed in circular inches.

[b] Representative values; exact values depend on insulation thickness to be used and will be furnished on request.

95. Hollow-core Stranded Conductors

(General Cable Corp.)

Size A.w.g. or cir. mils	Over-all conductor diam., in.		Size A.w.g. or cir. mils	Over-all conductor diam., in.	
	I.d. of spring core = 0.500 in.	I.d. of spring core = 0.690 in.		I.d. of spring core = 0.500 in.	I.d. of spring core = 0.690 in.
2/0	0.736	.....	700,000	1.151	1.256
3/0	0.768	0.924	750,000	1.180	1.286
4/0	0.807	0.956	800,000	1.212	1.309
250,000	0.837	0.983	850,000	1.242	1.341
300,000	0.880	1.017	900,000	1.261	1.365
350,000	0.917	1.049	1,000,000	1.310	1.416
400,000	0.953	1.082	1,250,000	1.434	1.524
450,000	0.989	1.112	1,500,000	1.547	1.635
500,000	1.028	1.145	1,750,000	1.650	1.730
600,000	1.084	1.201	2,000,000	1.760	1.833
650,000	1.121	1.228			

The above data are approximate and subject to normal manufacturing tolerances.

96. Iron or Steel Telephone and Telegraph Wire

(American Steel and Wire Co.)

Size, B.w.g.	Diam., in.	Approx. weight, lb.		Approx. breaking strength, lb.			Resistance per mile (International Ohms) at 68°F.		
		Per 1,000 ft.	Per mile	E. B. B.	B. B.	Steel	E. B. B.	B. B.	Steel
4	0.238	153	811	2,028	2,271	2,433	5.98	7.15	8.32
6	0.203	112	590	1,475	1,652	1,770	8.22	9.83	11.44
8	0.165	74	390	975	1,092	1,170	12.43	14.87	17.31
9	0.148	60	314	785	879	942	15.44	18.47	21.50
10	0.134	49	258	645	722	774	18.79	22.48	26.16
11	0.120	39	206	515	577	618	23.54	28.16	32.77
12	0.109	32	170	425	476	510	28.52	34.12	39.71
14	0.083	19	99	247	277	297	48.98	58.59	68.18

97. All-steel Conductors

(American Steel and Wire Co.)

Type	Size and diameter			Area		Approx. weight		Breaking strength, lb.
	Size, B.w.g.	Number and diameter of wires	Diam. of conductor, in.	Cir. mils	Sq. in.	Lb. per 1,000 ft.	Lb. per mile	
S	4	1	0.238	56,644	0.0445	153	808	5,560
S	6	1	0.203	41,209	0.0324	112	591	4,270
S	8	1	0.165	27,225	0.0214	74	391	2,820
S-3	4	3/0.138	0.297	57,132	0.0448	156	823	5,560
S-3	6	3/0.117	0.252	41,067	0.0322	112	591	4,270
S-3	8	3/0.096	0.207	27,648	0.0217	75	396	2,820

Modulus: Type S, 29,000,000; Type S-3, 25,000,000.
Coefficient of expansion: 0.0000066.

98. Hard-drawn Copper Trolley Wire

(General Cable Corp.)

Shape of conductor	Nominal conductor, size, C.M. or A.w.g.	Over-all diam., in.[a]	Area		Weight		Tensile strength, lb. per sq. in.	Breaking strength, lb.	Resistance, ohms per 1,000 ft., 68°F.
			Cir. mils	Sq. in.	Per 1,000 ft., net lb.	Per mile, net lb.			
Round	300,000	0.548	300,000	0.2356	908.1	4,795	46,400	10,930	0.03558
	4/0	0.460	211,600	0.1662	640.5	3,382	49,000	8,143	0.05044
	3/0	0.410	168,100	0.1320	508.8	2,687	51,000	6,732	0.06350
	2/0	0.365	133,200	0.1046	403.2	2,129	52,800	5,523	0.08014
	1/0	0.325	105,600	0.08294	319.7	1,688	54,500	4,520	0.1011
Grooved	350,000	0.620	351,200	0.2758	1063.0	5,612	42,800	11,800	0.03039
	300,000	0.574	299,800	0.2355	907.6	4,792	44,200	10,410	0.03560
	4/0	0.482	212,000	0.1665	641.9	3,389	46,600	7,759	0.05035
	3/0	0.430	167,300	0.1314	506.4	2,674	48,500	6,373	0.06380
	2/0	0.392	137,900	0.1083	417.6	2,205	50,200	5,437	0.07740
	1/0[b]	0.360	105,600	0.08294	319.7	1,688	51,800	4,296	0.1011
Figure Eight[b]	350,000	0.722 × 0.570	350,000	0.2749	1059.0	5,594	42,800	11,800	0.03050
	4/0	0.600 × 0.450	211,600	0.1662	640.5	3,382	46,600	7,745	0.05044
	3/0	0.540 × 0.400	168,100	0.1320	508.8	2,687	48,500	6,400	0.06350
	2/0	0.480 × 0.352	133,200	0.1046	403.2	2,129	50,200	5,250	0.08014
	1/0	0.420 × 0.312	105,600	0.08294	319.7	1,688	51,800	4,300	0.1011
Figure Nine, Deep Section[b]	400,000	0.750 × 0.5625	391,500	0.3075	1185.0	6,257	40,500	12,450	0.02726

The above data are approximate and subject to normal manufacturing tolerances.

[a] For Figs. 8 and 9 wire, dimensions given are nominal height of entire section and width of lower lobe. No. 6/0 A.w.g. (336,200 cir. mils) grooved or Fig. 8 will regularly be furnished in 350,000 cir. mils.

[b] Not at present included in A.S.T.M. Specification B 47.

99. Flat Bus-bar Copper

Size, in.	Weight, lb. per ft.	Area, cir. mils	Area, sq. in.
1/16 × 1/2	0.12	39,470	0.031
1/16 × 3/4	0.18	59,842	0.047
1/16 × 7/8	0.21	68,755	0.055
1/16 × 1	0.24	80,213	0.063
1/16 × 1 1/4	0.30	99,312	0.078
1/16 × 1 1/2	0.36	119,684	0.094
1/8 × 3/4	0.36	119,684	0.094
1/8 × 1	0.48	159,154	0.125
1/8 × 1 1/4	0.60	198,624	0.156
1/8 × 1 1/2	0.72	239,368	0.188
1/8 × 2	0.96	318,308	0.250
1/8 × 2 1/2	1.20	398,523	0.313
1/8 × 3	1.44	477,463	0.375
1/8 × 3 1/2	1.68	557,677	0.438
1/8 × 4	1.92	636,618	0.500
1/8 × 5	2.40	795,772	0.625
3/16 × 1	0.72	239,368	0.188
3/16 × 1 1/4	0.90	298,402	0.234
3/16 × 1 1/2	1.085	358,098	0.281
3/16 × 1 3/4	1.266	417,780	0.328
3/16 × 2	1.44	477,993	0.375
3/16 × 2 1/4	1.62	537,140	0.422
3/16 × 2 1/2	1.81	596,829	0.469
3/16 × 2 3/4	1.99	656,512	0.516
3/16 × 3	2.17	716,196	0.563
3/16 × 4	2.88	954,928	0.750
3/16 × 5	3.62	1,193,659	0.938
3/16 × 6	4.34	1,432,390	1.125
1/4 × 1	0.96	318,308	0.250
1/4 × 1 1/2	1.44	477,463	0.375
1/4 × 2	1.93	636,618	0.500
1/4 × 2 1/2	2.41	795,772	0.625
1/4 × 3	2.89	954,928	0.750
1/4 × 3 1/2	3.38	1,114,082	0.875
1/4 × 4	3.86	1,273,236	1.00
1/4 × 4 1/2	4.34	1,313,024	1.13
1/4 × 5	4.82	1,591,545	1.25
1/4 × 6	5.78	1,909,857	1.50
1/4 × 7	6.76	2,228,164	1.75
1/4 × 8	7.72	2,546,473	2.00
3/8 × 1 1/2	2.17	716,196	0.563
3/8 × 2	2.89	954,928	0.750
3/8 × 2 1/2	3.61	1,193,659	0.938
3/8 × 3	4.34	1,432,390	1.13
3/8 × 3 1/2	5.06	1,671,123	1.31
3/8 × 4	5.79	1,909,854	1.50
3/8 × 4 1/2	6.51	2,148,586	1.69
3/8 × 5	7.23	2,387,318	1.88
3/8 × 6	8.68	2,864,781	2.25
3/8 × 8	11.57	3,819,708	3.00
3/8 × 10	14.47	5,774,636	3.75
1/2 × 3	5.79	1,909,857	1.50
1/2 × 3 1/2	6.75	2,228,164	1.75
1/2 × 4	7.72	2,546,472	2.00
1/2 × 4 1/2	8.68	2,864,780	2.25
1/2 × 5	9.64	3,183,090	2.50
1/2 × 5 1/2	10.61	3,501,398	2.75
1/2 × 6	11.58	3,819,708	3.00
1/2 × 7	12.50	4,456,328	3.50
1/2 × 8	15.43	5,092,944	4.00
1/2 × 9	17.36	5,729,560	4.50
1/2 × 10	19.29	6,366,180	5.00

100. Round Copper Rod

Diameter		Approx. weight, lb. per ft.	Cir. mils, approx.	Cross section, sq. in. approx.
In.	Decimal equivalent			
1/8	0.125	0.047	15,600	0.01227
5/32	0.1562	0.077	24,400	0.01917
3/16	0.1875	0.106	35,000	0.02761
1/4	0.250	0.189	62,500	0.04909
5/16	0.3125	0.296	97,800	0.07670
3/8	0.375	0.426	140,000	0.11045
7/16	0.4375	0.580	191,800	0.15033
1/2	0.500	0.757	250,000	0.19635
9/16	0.5625	0.959	316,000	0.24850
5/8	0.625	1.184	390,000	0.30680
3/4	0.750	1.70	562,500	0.44179
7/8	0.875	2.32	765,000	0.60132
15/16	0.9375	2.68	880,000	0.69029
1	1.000	3.03	1,000,000	0.78540
1 1/8	1.125	3.83	1,270,000	0.99402
1 1/4	1.250	4.73	1,560,000	1.2272
1 3/8	1.375	5.73	1,900,000	1.4849
1 1/2	1.500	6.82	2,250,000	1.7671
1 5/8	1.625	8.04	2,650,000	2.0739
1 11/16	1.6875	8.68	2,850,000	2.2365
1 3/4	1.750	9.28	3,070,000	2.4053
1 7/8	1.875	10.72	3,500,000	2.7612
2	2.000	12.12	4,000,000	3.1416
2 1/2	2.500	19.05	6,250,000	4.9087
3	3.000	27.44	9,000,000	7.0686
3 1/2	3.500	37.23	12,250,000	9.6211

101. Copper Tubing—Standard Iron-pipe Size

Size, in.	Approx. o.d.	O.d.	I.d.	Wall thickness	Weight, lb. per ft.	Area, cir. mils	Area, sq. in.
1/8	13/32	0.405	0.281	0.062	0.259	85,064	0.066
1/4	17/32	0.540	0.375	0.082	0.459	150,000	0.117
3/8	11/16	0.675	0.484	0.095	0.644	221,369	0.173
1/2	27/32	0.840	0.625	0.107	0.958	314,975	0.246
3/4	1 1/16	1.050	0.822	0.114	1.298	426,816	0.335
1	1 5/16	1.315	1.062	0.126	1.829	601,381	0.470
1 1/4	1 43/64	1.660	1.368	0.146	2.689	884,176	0.694
1 1/2	1 29/32	1.900	1.600	0.150	3.193	1,050,000	0.824
2	2 3/8	2.375	2.062	0.156	4.224	1,388,781	1.087
2 1/2	2 7/8	2.875	2.500	0.187	6.130	2,015,625	1.579
3	3 1/2	3.500	3.062	0.219	8.741	2,874,156	2.257
3 1/2	4	4.000	3.500	0.250	11.41	3,750,000	2.945
4	4 1/2	4.500	4.000	0.250	12.93	4,250,000	3.337

102. Copper Tubing—Extra-heavy Iron-pipe Size

Size, in.	Approx. o.d.	O.d.	I.d.	Wall thickness	Weight, lb. per ft.	Area, cir. mils	Area, sq. in.
⅛	13/32	0.405	0.205	0.100	0.371	122,000	0.095
¼	35/64	0.540	0.294	0.123	0.624	205,164	0.161
⅜	11/16	0.675	0.421	0.127	0.847	278,384	0.218
½	27/32	0.840	0.542	0.149	0.253	411,836	0.323
¾	1 1/16	1.050	0.736	0.157	1.706	560,804	0.440
1	1 5/16	1.315	0.951	0.182	2.509	824,849	0.647
1¼	1 43/64	1.660	1.272	0.194	3.460	1,137,616	0.893
1½	1 29/32	1.900	1.494	0.203	4.191	1,377,858	1.082
2	2 3/8	2.375	1.933	0.221	5.791	1,904,140	1.495
2½	2 7/8	2.875	2.315	0.280	8.839	2,906,500	2.282
3	3½	3.500	2.892	0.304	11.82	3,886,320	3.052
3½	4	4.000	3.358	0.321	14.37	4,723,820	3.710
4	4½	4.500	3.818	0.341	17.25	5,672,860	4.455

103. Copper Tubing—Double Extra-heavy Iron-pipe Size

Size, in.	Approx. o.d.	O.d.	I.d.	Wall thickness	Weight, lb. per ft.	Area, cir. mils	Area, sq. in.
½	27/32	0.840	0.252	0.294	1.945	642,096	0.504
¾	1 1/16	1.050	0.434	0.308	2.768	914,144	0.718
1	1 5/16	1.315	0.599	0.358	4.152	1,370,449	1.076
1¼	1 43/64	1.660	0.896	0.382	5.916	1,952,784	1.534
1½	1 29/32	1.900	1.100	0.400	7.271	2,410,000	1.885
2	2 3/8	2.375	1.503	0.436	10.246	3,381,620	2.656
2½	2 7/8	2.875	1.771	0.552	15.541	5,130,300	4.028
3	3½	3.500	2.300	0.600	21.087	6,960,000	5.466
3½	4	4.000	2.728	0.636	25.930	8,568,000	6.721
4	4½	4.500	3.152	0.674	31.253	10,314,080	8.101

104. General Characteristics of Copperweld Wire

Grade	Conductivity, per cent	Density	Weight per cir. mil per 1,000 ft., lb.	Tensile strength per sq. in., 0.162-in. wire, lb.	Normal resistivity per cir. mil-ft., at 68°F., ohms
Extra high strength	30	8.15	0.002775	157,000	34.57
High strength	30	8.15	0.002775	130,000	34.57
High strength	40	8.15	0.002775	118,000	25.928

Modulus of elasticity (conventional):
Solid wire..... 24,000,000 lb. per sq. in.
Stranded cable..... 23,000,000 lb. per sq. in.
Coefficient of linear expansion per degree Fahrenheit: 0.0000072.
Thirty per cent conductivity is not recommended in sizes finer than No. 10 A.w.g.
Finer sizes are supplied in 40 per cent conductivity only.

105. Application Guide for Copperweld Products

Product	Companies and uses					
	Power	Railroad	Electric railway	Telephone and telegraph	Municipal	Mill, etc.
Bare wire	Telephone and signal lines Overhead ground Grounding wire Lightly loaded lines Tie wires, mousing wire Light guys Remote-control lines	Signal, telegraph and telephone lines Control circuits Overhead ground Grounding wire Bond wires Tie wires C. t. c. circuits	Telephone and signal lines Overhead ground Light span wire Light guys	Line wires Guys	Police and fire alarm circuits	Telephone lines Grounding wire Crane trolley Pipe insulation wrapping wire
Weatherproof, double and triple braid	Telephone and signal lines Remote control	Signal lines Control circuits Tie wires C. t. c. circuits	Telephone and signal lines	Tree wire Grounding wire Line wire Drop wires	Signal and alarm circuits Tie wires	Signal and alarm circuits
Rubber covered, single, parallel pair, twisted pair	Telephone and signal lines Drop wires	Telephone and signal lines Drop wires	Telephone lines Drop wires	Drop wires	Alarm circuits Drop wires	Telephone and signal lines Drop wires
Strand 3-7-19 wire, etc	Guy and messenger Overhead ground Power and telephone Long spans Stack guys	Rail bonds Guy and messenger Overhead ground Long spans Pull-offs for electrifications	Span wire Guy wire Catenary messenger Pull-offs Overhead ground	Guy and messenger Long spans	Guy and messenger Long spans	Guy and messenger Overhead ground Stack guys Long spans

Cables, composite strands	Copperweld-copper cables of numerous combinations for long spans, rural distribution, and transmission conductors	Copperweld-copper Catenary messenger Feeder cables for electrification	Copperweld-copper Catenary messenger Feeder cables	.....	.....	Copperweld-copper Cables for long spans
Ground rods and clamps	For all protective grounding installations, where artificial or driven grounds are required					
Anchor rods	For all types of anchors and anchoring installations					
Cable rings and marline hangers	Available in all standard types of rings, standard and extra-long					
Fencing and barbed wire	Wherever high strength, nonrusting property protection is required Available in any form of fencing made from wire					
Staples, nails	Grounding wire molding, pole steps, insulator pins, etc.	Grounding wire, pole steps, insulator pins, trunking, conduit, battery racks, bond wires to ties, etc.	Grounding wire, pole steps, insulator pins, etc.	Grounding wire, insulator pins, pole steps, conduit, etc.	Grounding wire, conduit, etc.	Roofs and building

Copperweld is also extensively used by mines and collieries, cement companies, state forestries, and game and fisheries for telephone and signal lines and grounding; by broadcasting stations and individuals for radio antennas, leadin, grounding, etc.; in the home for clothes lines, and nails for slate, tile, and composition roofs.

106. Solid Copperweld Conductors

Size, A.w.g.	Diam., in.	Area		Weight		Tensile strength, nominal			Breaking strength		
		Cir. mils	Sq. in.	Per 1,000 ft., lb.	Per mile, lb.	30% extra high strength, lb. per sq. in.	30% high strength, lb. per sq. in.	40% high strength, lb. per sq. in.	30% extra high strength, lb.	30% high strength, lb.	40% high strength, lb.
4/0	0.460	211,600	0.1662	587	3,100	.....	90,000	80,000	.....	14,960	13,290
3/0	0.410	168,100	0.1320	466	2,460	.....	90,000	80,000	.....	11,880	10,560
2/0	0.365	133,225	0.1046	370	1,954	.....	90,000	80,000	.....	9,410	8,370
1/0	0.325	105,625	0.08296	293	1,547	.....	94,000	82,000	.....	7,800	6,800
1	0.289	83,520	0.06560	232	1,225	.....	102,000	90,000	.....	6,690	5,900
2	0.258	66,565	0.05228	185	977	123,000	109,000	97,000	6,430	5,700	5,070
3	0.229	52,440	0.04119	146	771	133,500	115,000	103,000	5,490	4,740	4,240
4	0.204	41,615	0.03269	116	612	142,500	120,000	108,000	4,660	3,920	3,530
5	0.182	33,125	0.02602	91.9	485	150,500	125,000	113,000	3,910	3,250	2,940
6	0.162	26,245	0.02061	72.8	384	157,000	130,000	118,000	3,240	2,680	2,430
7	0.144	20,735	0.01629	57.5	304	164,000	135,000	123,000	2,670	2,200	2,000
8	0.128	16,385	0.01287	45.5	240	170,000	140,000	128,000	2,190	1,800	1,650
9	0.114	12,995	0.01021	36.1	191	.....	145,000	133,000	.....	1,480	1,360
10	0.102	10,404	0.00817	28.9	153	.....	150,000	138,000	.....	1,230	1,130
11	0.091	8,281	0.00650	23.0	121	.....	.....	138,000	.....	.....	900
12	0.081	6,561	0.00515	18.2	96	.....	.....	138,000	.....	.....	710

107. Composite Copper-copperweld Bare Conductors
(General Cable Corp.)

Equivalent hard-drawn copper, size, C.M. or A.w.g.	Type of conductor	Number and diam. of strands		Area		Overall diam., mils	Cable weight		Breaking strength, lb.	Resistance, ohms per 1,000 ft., 68°F.
		Hard-drawn copper	Copperweld, 30% extra high strength	Cir. mils	Sq. in.		Per 1,000 ft., lb.	Per mile, lb.		
586,800	E	12/0.2043	7/0.2043	790,800	0.6211	1.020	2,358	12,450	50,530	0.0180
467,100	E	12/0.1819	7/0.1819	629,500	0.4944	0.910	1,874	9,895	41,800	0.0227
370,100	E	12/0.1620	7/0.1620	498,600	0.3916	0.810	1,486	7,846	34,240	0.0286
292,400	E	12/0.1443	7/0.1443	394,100	0.3095	0.720	1,175	6,193	27,940	0.0362
231,000	E	12/0.1285	7/0.1285	311,300	0.2445	0.640	927	4,894	22,650	0.0458
4/0	E	12/0.1229	7/0.1229	284,900	0.2238	0.615	848	4,476	20,720	0.0496
4 0	F	6/0.1833	1/0 1883	235,100	0.1847	0.550	712	3,760	12,290	0.0512
4 0	Special	7/0.1697	3/0.1050	234,700	0.1843	0.566	716	3,781	12,810	0.05123
250,000	Special	7/0.1845	3/0.1142	277,400	0.2179	0.615	846	4,469	15,000	0.04335
183,200	E	12/0.1144	7/0.1144	247,000	0.1940	0.570	736	3,886	18,400	0.0578
3/0	E	12/0.1091	7/0.1091	226,100	0.1776	0.545	672	3,748	16,800	0.0646
3 0	F	6/0.1631	1/0.1631	186,400	0.1463	0.489	563	2,973	9,970	0.0632
146,700	E	12/0.1019	7/0.1019	197,600	0.1552	0.510	589	3,110	14,920	0.0721
2/0	F	6/0.1454	1/0.1454	147,900	0.1161	0.436	447	2,359	8,090	0.0814
1/0	F	6/0.1294	1/0.1294	117,200	0.09200	0.388	354	1,870	6,536	0.103
1	F	6/0.1152	1/0.1152	92,990	0.07294	0.346	280	1,481	5,260	0.129
2	F	6/0.1026	1/0.1026	73,740	0.05789	0.308	223	1,175	4,230	0.163
2	A	2/0.1699	1/0.1699	86,570	0.06799	0.366	256.8	1,356	5,876	0.160
3	A	2/0.1513	1/0.1513	68,660	0.05392	0.326	203.6	1,075	4,810	0.203
4	A	2/0.1347	1/0.1347	54,440	0.04276	0.290	161.5	852.8	3,938	0.256
5	A	2/0.1200	1/0.1200	43,170	0.03391	0.258	128.1	676.3	3,193	0.322
6	A	2/0.1068	1/0.1068	34,240	0.02689	0.230	101.6	536.3	2,585	0.406
7	A	2/0.0895	1/0.1266	32,200	0.02516	0.223	93.66	494.6	2,754	0.511
8	A	2/0.0797	1/0.1127	25,500	0.01995	0.199	74.27	392.2	2,233	0.646

Type conductor	Number of strands	Moduli (conventional) lb. per sq. in.	Coefficients of linear expansion, per °F.
E	19	19,000,000	0.0000084
F	7	17,100,000	0.0000089
2A–6A	3	19,000,000	0.0000085
7A–8A	3	20,500,000	0.0000081
Special	10	16,500,000	0.0000090

The above data are approximate and subject to normal manufacturing tolerances.

Type E (19-strand cables) consists of 7-strand concentric-stranded core of copperweld and outer layer of 12 copper strands.

Type F (7-strand cables) consists of inner strand copperweld and outer layer of six copper strands.

Type A (3-strand cables) consists of three wires cabled together, two of hard-drawn copper and one of extra high strength copperweld.

Special (10-strand cables) consists of three copperweld wires cabled together as a core covered by seven copper wires.

108. Stranded Copperweld Conductors

Nominal diam. in., number of strands, and size A.w.g.	Diam., in.	Area		Weight		Breaking strength		
		Cir. mils	Sq. in.	Per 1000 ft., lb.	Per mile, lb.	30% extra high strength, lb.	30% high strength, lb.	40% high strength, lb.
7/8 (19 No. 5)	0.910	629,375	0.4944	1,770	9,346	66,860	55,570	50,270
13/16 (19 No. 6)	0.810	498,655	0.3916	1,403	7,408	55,400	45,880	41,550
23/32 (19 No. 7)	0.720	393,695	0.3095	1,108	5,850	45,660	37,620	34,200
21/32 (19 No. 8)	0.640	311,315	0.2445	877	4,630	37,450	30,780	28,210
9/16 (19 No. 9)	0.570	246,905	0.1940	696	3,675	30,610	25,300	23,250
5/8 (7 No. 4)	0.612	291,305	0.2288	820	4,330	29,360	24,700	22,240
9/16 (7 No. 5)	0.546	231,875	0.1821	650	3,432	24,630	20,480	18,500
1/2 (7 No. 6)	0.486	183,715	0.1443	515	2,720	20,410	16,880	15,300
7/16 (7 No. 7)	0.432	145,145	0.1140	407	2,149	16,820	13,860	12,600
3/8 (7 No. 8)	0.384	114,695	0.0901	322	1,700	13,800	11,340	10,390
11/32 (7 No. 9)	0.342	90,965	0.0715	255	1,346	11,280	9,320	8,570
5/16 (7 No. 10)	0.306	72,828	0.0572	204	1,077	9,200	7,750	7,120
3 No. 6	0.349	78,735	0.0618	220	1,162	8,260	6,830	6,200
3 No. 7	0.310	62,205	0.0489	174	919	6,800	5,610	5,100
3 No. 8	0.276	49,155	0.0386	138	729	5,580	4,590	4,210
3 No. 9	0.246	38,985	0.0306	109	576	4,560	3,770	3,470
3 No. 10	0.220	31,212	0.0245	87	460	3,720	3,140	2,880
3 No. 11	0.196	24,843	0.0195	69.6	367	.....	.....	2,480
3 No. 12	0.175	19,683	0.01545	55.0	290	.....	.....	2,040

To determine copper equivalent of copperweld conductor, multiply circular-mil area by percentage conductivity expressed as a decimal.

109. Comparative Characteristics of Aluminum and Copper Wire

Characteristic	Commercial hard-drawn aluminum wire	Commercial hard-drawn copper wire	Standard annealed copper wire
Conductivity	60.97% of I.A.C.S.	97% of I.A.C.S.	100% of I.A.C.S.
Resistance per circular mil-foot	17.010 ohms	10.692 ohms	10.371 ohms
Temperature coefficient of resistance	0.403% per °C.	0.393% per °C.	0.393% per °C.

110. All-aluminum Bare Wire
(Aluminum Co. of America)

Aluminum			Copper equivalent, cir. mils or A.w.g.	Stranding	Ultimate strength, lb.	Diam., in.	Weight, lb.	
B. & S. gage No.	Area						Per 1,000 ft.	Per mile
	Cir. mils	Sq. in.						
	1,590,000	1.249	1,000,900	61/0.1615	30,000	1.454	1,492	7,878
	1,510,500	1.186	950,000	61/0.1574	28,500	1.417	1,418	7,484
	1,431,000	1.124	900,000	61/0.1532	27,000	1.379	1,343	7,091
	1,351,500	1.062	850,000	61/0.1489	26,000	1.340	1,268	6,696
	1,272,000	0.9990	800,000	61/0.1444	24,500	1.300	1,194	6,302
	1,192,500	0.9366	750,000	61/0.1398	23,400	1.258	1,119	5,908
	1,113,000	0.8741	700,000	61/0.1351	21,850	1.216	1,044	5,514
	1,033,500	0.8117	650,000	37/0.1672	19,480	1.170	970	5,121
	954,000	0.7493	600,000	37/0.1606	17,980	1.124	895	4,726
	874,500	0.6868	550,000	37/0.1538	16,480	1.077	821	4,333
	795,000	0.6244	500,000	37/0.1466	15,300	1.026	746	3,939
	750,000	0.5890	472,000	37/0.1424	14,430	0.997	704	3,716
	715,500	0.5620	450,000	37/0.1391	14,050	0.974	671	3,545
	636,000	0.4995	400,000	37/0.1311	12,490	0.918	597	3,151
	556,500	0.4371	350,000	19/0.1711	10,490	0.856	522	2,757
	500,000	0.3927	314,500	19/0.1623	9,425	0.812	469	2,477
	477,000	0.3746	300,000	19/0.1585	8,990	0.793	447.6	2,363
	397,500	0.3122	250,000	19/0.1447	7,650	0.724	373.0	1,969
	336,400	0.2642	4/0	19/0.1331	6,605	0.666	315.7	1,667
	300,000	0.2356	188,800	19/0.1257	5,890	0.629	281.5	1,486
	266,800	0.2095	3/0	7/0.1953	5,030	0.586	249.1	1,315
4/0	211,600	0.1662	2/0	7/0.1739	3,990	0.522	197.6	1,043
3/0	167,806	0.1318	1/0	7/0.1548	3,160	0.464	156.7	827
2/0	133,077	0.1045	1	7/0.1379	2,610	0.414	124.3	656
1/0	105,535	0.0829	2	7/0.1228	2,070	0.368	98.5	520
1	83,693	0.0657	3	7/0.1094	1,710	0.328	78.1	412
2	66,371	0.0521	4	7/0.0974	1,405	0.292	62.0	327
3	52,635	0.0413	5	7/0.0867	1,135	0.260	49.2	260
4	41,741	0.0328	6	7/0.0772	918	0.232	39.0	206

111. Aluminum Cable, Steel—Reinforced, Bare
(Aluminum Co. of America)

Cross-section areas			Copper equivalent, cir. mils or A.w.g.	Stranding number and diam., of strands, in.		Diam., in.		Ultimate strength, lb.	Total weight, lb.	
Aluminum		Total,		Aluminum	Steel	Complete cable	Steel core		Per 1,000 ft.	Per mile
Cir. mils	Sq. in.	Sq. in.								
1,590,000	1.249	1.4070	1,000,000	54/0.1716	19/0.1030	1.545	0.515	56,000	2,041	10,777
1,510,500	1.186	1.3366	950,000	54/0.1673	19/0.1004	1.506	0.502	53,200	1,939	10,237
1,431,000	1.124	1.2663	900,000	54/0.1628	19/0.0977	1.465	0.489	50,400	1,837	9,699
1,351,500	1.062	1.1959	850,000	54/0.1582	19/0.0949	1.424	0.475	47,600	1,735	9,160
1,272,000	0.9990	1.1256	800,000	54/0.1535	19/0.0921	1.382	0.461	44,800	1,633	8,621
1,192,500	0.9366	1.0552	750,000	54/0.1486	19/0.0892	1.338	0.446	43,100	1,531	8,082
1,113,000	0.8741	0.9849	700,000	54/0.1436	19/0.0862	1.293	0.431	40,200	1,429	7,544
1,033,500	0.8117	0.9169	650,000	54/0.1384	7/0.1384	1.246	0.415	37,100	1,330	7,019
954,000	0.7493	0.8464	600,000	54/0.1329	7/0.1329	1.196	0.399	34,200	1,227	6,479
900,000	0.7069	0.7985	566,000	54/0.1291	7/0.1291	1.162	0.387	32,300	1,158	6,112
874,500	0.6868	0.7759	550,000	54/0.1273	7/0.1273	1.146	0.382	31,400	1,125	5,940
795,000	0.6244	0.7053	500,000	54/0.1214	7/0.1214	1.093	0.364	28,500	1,023	5,399
795,000	0.6244	0.7261	500,000	26/0.1749	7/0.1360	1.108	0.408	31,200	1,093	5,770
795,000	0.6244	0.7668	500,000	30/0.1628	19/0.0977	1.140	0.489	38,400	1,234	6,517
715,500	0.5620	0.6348	450,000	54/0.1151	7/0.1151	1.036	0.345	26,300	921	4,859
715,500	0.5620	0.6535	450,000	26/0.1659	7/0.1290	1.051	0.387	28,100	984	5,193
715,500	0.5620	0.6901	450,000	30/0.1544	19/0.0926	1.081	0.463	34,600	1,111	5,865
666,600	0.5235	0.5914	419,000	54/0.1111	7/0.1111	1.000	0.333	24,500	858	4,527
636,000	0.4995	0.5643	400,000	54/0.1085	7/0.1085	0.977	0.326	23,600	818	4,319
636,000	0.4995	0.5809	400,000	26/0.1564	7/0.1216	0.990	0.365	25,000	874	4,616

605,000	0.4752	0.5368	380,500	54/0.1059	7/0.1059	0.953	0.318	22,500	779	4,109
605,000	0.4752	0.5526	380,500	26/0.1525	7/0.1186	0.970	0.356	24,100	832	4,391
556,500	0.4371	0.5083	350,000	26/0.1463	7/9.1138	0.927	0.341	22,400	765	4,039
556,500	0.4371	0.5391	350,000	30/0.1362	7/0.1362	0.953	0.409	27,200	869	4,588
500,000	0.3927	0.4843	314,500	30/0.1291	7/0.1291	0.904	0.3873	24,400	780.7	4,122
477,000	0.3746	0.4356	300,000	26/0.1355	7/0.1054	0.858	0.3162	19,430	655.7	3,462
477,000	0.3746	0.4620	300,000	30/0.1261	7/0.1261	0.883	0.3783	23,300	744.8	3,933
397,500	0.3122	0.3630	250,000	26/0.1236	7/0.0961	0.783	0.2883	16,190	546.4	2,885
397,500	0.3122	0.3850	250,000	30/0.1151	7/0.1151	0.806	0.3453	19,980	620.6	3,277
336,400	0.2642	0.3072	4/0	26/0.1138	7/0.0885	0.721	0.2655	14,050	462.4	2,442
336,400	0.2642	0.3259	4/0	30/0.1059	7/0.1059	0.741	0.3177	17,040	525.3	2,774
300,000	0.2356	0.2740	188,700	26/0.1074	7/0.0835	0.680	0.2505	12,650	412.4	2,178
300,000	0.2356	0.2906	188,700	30/0.1000	7/0.1000	0.700	0.3000	15,430	468.4	2,473
266,800	0.2095	0.2367	3/0	6/0.2109	7/0.0703	0.633	0.2109	9,645	341.3	1,802
266,800	0.2095	0.2436	3/0	26/0.1013	7/0.0788	0.642	0.2364	11,250	366.8	1,936
4/0	0.1662	0.1939	2/0	6/0.1878	1/0.1878	0.563	0.1878	8,420	292.1	1,542
3/0	0.1318	0.1538	1/0	6/0.1672	1/0.1672	0.502	0.1672	6,675	231.6	1,223
2/0	0.1045	0.1219	1	6/0.1490	1/0.1490	0.447	0.1490	5,345	183.7	970
1/0	0.0829	0.0967	2	6/0.1327	1/0.1327	0.398	0.1327	4,280	145.6	769
1	0.0657	0.0767	3	6/0.1182	1/0.1182	0.355	0.1182	3,480	115.5	610
2	0.0521	0.0653	4	7/0.0974	1/0.1299	0.325	0.1299	3,535	107.2	566
2	0.0521	0.0608	4	6/0.1052	1/0.1052	0.316	0.1052	2,790	91.6	484
3	0.0413	0.0482	5	6/0.0937	1/0.0937	0.281	0.0937	2,250	72.7	384
4	0.0328	0.0411	6	7/0.0772	1/0.1029	0.257	0.1029	2,288	67.4	356
4	0.0328	0.0383	6	6/0.0834	1/0.0834	0.250	0.0834	1,830	57.6	304
5	0.0260	0.0303	7	6/0.0743	1/0.0743	0.223	0.0743	1,460	45.7	241
6	0.0206	0.0240	8	6/0.0661	1/0.0661	0.198	0.0661	1,170	36.2	191
7	0.0163	0.0190	9	6/0.0589	1/0.0589	0.177	0.0589	935	28.7	151
8	0.0130	0.0152	10	6/0.0525	1/0.0525	0.158	0.0525	745	22.8	120

112. Copper-steel Conductors

(American Steel and Wire Co.)

Size, S.C.P. or S.C.G.	Equivalent to hard-drawn copper		Approx. diam., in.		Modulus of elasticity	Min. breaking strength, lb.	Approx. weight, lb.		Total cross-sectional area	
	Size, A.w.g.	Cir. mils	Strand	Each wire			Per 1,000 ft.	Per mile	Cir. mils	Sq. in.
2	2	66,370	0.392	0.182	19,800,000	6,378	291	1,536	99,372	0.0781
4	4	41,740	0.310	0.144	19,800,000	4,486	182	961	62,208	0.0489
6	6	26,250	0.248	0.115	19,800,000	3,060	116	613	39,675	0.0312
8	8	16,510	0.196	0.091	20,500,000	2,112	73	385	24,843	0.0195
10[a]	10	10,380	0.220	0.1019	21,700,000	3,853	88	464	31,140	0.0244
12[a]	12	6,530	0.172	0.0808	21,700,000	2,426	55	290	19,590	0.0154

Coefficient of linear expansion:
Sizes 2 to 8—0.0000082 per °F.; sizes 10 to 12—0.0000075 per °F.
[a] Made up of one copper and two steel.

113. Thickness of Rubber Insulation Required for Wires of Types R, RH

(National Board of Fire Underwriters)

Size of conductor, A.w.g. and cir. mils	Thickness, in., for voltages not over					
	600 volts	1,000 volts	2,000 volts	3,000 volts	4,000 volts	5,000 volts
14–12	2/64	4/64	5/64	7/64	9/64	10/64
10	3/64	4/64	5/64	7/64	9/64	10/64
8	4/64	5/64	6/64	7/64	9/64	10/64
6–2	4/64	5/64	6/64	8/64	9/64	10/64
1–4/0	5/64	6/64	7/64	8/64	9/64	10/64
213,000–500,000	6/64	7/64	8/64	9/64	10/64	11/64
501,000–1,000,000	7/64	8/64	9/64	9/64	10/64	11/64
Over 1,000,000	8/64	9/64	9/64	10/64	11/64	12/64

114. Thickness of Insulation Required for Wires of Types RW, RU, RUW, T, TW, and TA

(National Board of Fire Underwriters)

Size of conductor, A.w.g.	Thickness, in., for 600 volts			
	RW	T, TW	RU, RUW	TA
14–10	3/64	2/64	18 mils	20 mils
8	4/64	3/64	25 mils	20 mils
6–2	4/64	4/64	25 mils	Thermoplastic 30 mil Asbestos 25 mils
1–4/0	5/64	5/64	.....	Thermoplastic 40 mil Asbestos 30 mils
213,000–500,000	6/64	6/64		
501,000–1,000,000	7/64	7/64		
1,001,000–2,000,000	8/64	8/64		

115. Thickness of Varnished-cambric Insulation Required
(National Board of Fire Underwriters)

Rated voltage, phase to phase, volts	Size, A.w.g. or 1,000 cir. mils	Thickness of insulation		
		Single-conductor cables, in.	Multiconductor cables	
			Individual conductors, in.	Over-all belt, in.
0–600	14–8	3/64	3/64	None
	6–2	4/64	4/64	None
	1–4/0	5/64	5/64	None
	213–500	6/64	6/64	None
	501–1,000	7/64	6/64	3/64
	Over 1,000	8/64	7/64	3/64
601–1,000	14–2	4/64	4/64	None
	1–4/0	5/64	5/64	None
	213–500	6/64	6/64	None
	501–1,000	7/64	6/64	3/64
	Over 1,000	8/64	7/64	3/64
1,001–2,000	12–2	5/64	5/64	None
	1–500	6/64	6/64	None
	501–1,000	7/64	6/64	3/64
	Over 1,000	8/64	7/64	3/64
2,001–3,000	10–2	6/64	5/64	3/64
	1–4/0	6/64	6/64	3/64
	213–500	7/64	6/64	3/64
	501–1,000	7/64	6/64	3/64
	Over 1,000	8/64	7/64	3/64
3,001–4,000	8–4/0	7/64	6/64	3/64
	213–500	8/64	6/64	3/64
	501–1,000	8/64	6/64	4/64
	Over 1,000	9/64	7/64	4/64
4,001–5,000	8–4/0	9/64	6/64	4/64
	213–1,000	10/64	7/64	4/64
	Over 1,000	10/64	7/64	5/64

The voltages referred to in the table are the operating voltages between phases of single and two-phase systems, and three-phase systems with grounded or ungrounded neutral.

116. Standard Insulation Thicknesses for Single-conductor Cable or Multiple-conductor Type H (Shielded) Cable

(General Cable Corp.)

Rated voltage, phase to phase	Size of conductor, A.w.g. or 1,000 cir. mils	Paper, solid				Varnished cambric				Rubber			
		Grounded neutral		Ungrounded neutral		Grounded neutral		Ungrounded neutral		Grounded neutral		Ungrounded neutral	
		In.	Mils	In.	Mils	In	Mils	In.	Mils	In.	Mils	In.	Mils
600	14–9	....	...	.....	...	3/64	47	3/64	47	3/64	47	3/64	47
	8	4/64	63	4/64	63	3/64	47	3/64	47	4/64	63	4/64	63
	7–2	4/64	63	4/64	63	4/64	63	4/64	63	4/64	63	4/64	63
	1–4/0	4/64	63	4/64	63	5/64	78	5/64	78	5/64	78	5/64	78
	213– 500	4/64	63	4/64	63	6/64	94	6/64	94	6/64	94	6/64	94
	501–1,000	5/64	78	5/64	78	7/64	109	7/64	109	7/64	109	7/64	109
	Over 1,000	6/64	94	6/64	94	8/64	125	8/64	125	8/64	125	8/64	125
1,000	14–9	...	...	....	...	4/64	63	4/64	63	4/64	63	4/64	63
	8	4/64	63	4/64	63	4/64	63	4/64	63	4/64	63	4/64	63
	7–2	4/64	63	4/64	63	4/64	63	4/64	63	5/64	78	5/64	78
	1–4/0	4/64	63	4/64	63	5/64	78	5/64	78	6/64	94	6/64	94
	213– 500	4/64	63	4/64	63	6/64	94	6/64	94	7/64	109	7/64	109
	501–1,000	5/64	78	5/64	78	7/64	109	7/64	109	8/64	125	8/64	125
	Over 1,000	6/64	94	6/64	94	8/64	125	8/64	125	8/64	141	8/64	141
2,000	14–13	...	...	....	...	....	...	....	...	5/64	78	5/64	78
	12–9	...	...	....	...	5/64	78	5/64	78	5/64	78	5/64	78
	8	5/64	78	5/64	78	5/64	78	5/64	78	5/64	78	5/64	78
	7–2	5/64	78	5/64	78	5/64	78	5/64	78	6/64	94	6/64	94
	1–4/0	5/64	78	5/64	78	6/64	94	6/64	94	7/64	109	7/64	109
	213– 500	6/64	78	5/64	78	6/64	94	6/64	94	8/64	125	8/64	125
	501–1,000	6/64	94	6/64	94	7/64	109	7/64	109	8/64	141	8/64	141
	Over 1,000	7/64	109	7/64	109	8/64	125	8/64	125	8/64	141	8/64	141
3,000	14–11	...	...	....	...	....	...	....	...	7/64	109	7/64	109
	10–9	...	...	....	...	6/64	94	6/64	94	7/64	109	7/64	109
	8	5/64	78	5/64	78	6/64	94	6/64	94	7/64	109	7/64	109
	7–4/0	6/64	78	5/64	78	6/64	94	6/64	94	8/64	125	8/64	125
	213– 500	6/64	78	5/64	78	7/64	109	7/64	109	8/64	141	8/64	141
	501–1,000	6/64	94	6/64	94	7/64	109	7/64	109	8/64	141	8/64	141
	Over 1,000	7/64	109	7/64	109	8/64	125	8/64	125	10/64	156	10/64	156
4,000	14–9	...	...	....	...	....	...	....	...	8/64	141	8/64	141
	8–4/0	6/64	94	6/64	94	7/64	109	7/64	109	8/64	141	8/64	141
	213–1,000	6/64	94	6/64	94	8/64	125	8/64	125	10/64	156	10/64	156
	Over 1,000	7/64	109	7/64	109	8/64	141	8/64	141	11/64	172	11/64	172
5,000	14–9	...	...	....	...	....	...	....	...	10/64	156	10/64	156
	8–4/0	6/64	94	6/64	94	8/64	125	8/64	141	10/64	156	10/64	156
	213–1,000	6/64	94	6/64	94	8/64	141	10/64	156	11/64	172	11/64	172
	Over 1,000	7/64	109	7/64	109	8/64	141	10/64	156	12/64	188	12/64	188
6,000	14–9	...	...	....	...	....	...	....	...	10/64	156	12/64	188
	8–4/0	7/64	109	7/64	109	8/64	141	10/64	156	10/64	156	12/64	188
	213–1,000	7/64	109	7/64	109	8/64	141	11/64	172	11/64	172	12/64	188
	Over 1,000	8/64	125	8/64	125	8/64	141	11/64	172	12/64	188	13/64	203
7,000	8–1,000	8/64	125	8/64	141	10/64	156	11/64	172	11/64	172	14/64	219
	Over 1,000	8/64	125	8/64	141	10/64	156	11/64	172	12/64	188	15/64	234
8,000	8–7	...	...	....	...	....	...	....	...	12/64	188	16/64	250
	6–1,000	8/64	141	10/64	156	11/64	172	12/64	188	12/64	188	16/64	250
	Over 1,000	8/64	141	10/64	156	11/64	172	12/64	188	13/64	203	17/64	266
9,000	6–1,000	8/64	141	11/64	172	11/64	172	13/64	203	13/64	203	17/64	266
	Over 1,000	8/64	141	11/64	172	11/64	172	13/64	203	14/64	219	18/64	281

Standard Insulation Thicknesses for Single-conductor Cable or Multiple-conductor Type H (Shielded) Cable (*Continued*)

Rated voltage, phase to phase	Size of conductor,[a] A.w.g., or 1,000 cir. mils	Paper					Varnished cambric				Rubber			
		Oil-filled,[a] grounded neutral, mils	Solid											
			Grounded neutral		Ungrounded neutral		Grounded neutral		Ungrounded neutral		Grounded neutral		Ungrounded neutral	
			In.	Mils	In.	Mils	In.	Mils	In.	Mils	In.	Mils	In.	Mils
10,000	6–1,000	...	10/64	156	12/64	188	12/64	188	15/64	234	14/64	219	18/64	281
	Over 1,000	...	19/64	156	13/64	188	12/64	188	15/64	234	15/64	234	19/64	297
11,000	6–1,000	...	10/64	156	12/64	188	13/64	203	16/64	250	15/64	234	20/64	313
	Over 1,000	...	19/64	156	12/64	188	13/64	203	16/64	250	19/64	250	21/64	328
12,000	6–1,000	...	11/64	172	13/64	203	14/64	219	16/64	250	16/64	250	22/64	344
	Over 1,000	...	11/64	172	13/64	203	14/64	219	16/64	250	17/64	266	23/64	359
13,000	6–1,000	...	11/64	172	14/64	219	15/64	234	18/64	281	17/64	266	23/64	359
	Over 1,000	...	11/64	172	14/64	219	15/64	234	18/64	281	18/64	281	24/64	375
14,000	6–1,000	...	12/64	188	15/64	234	15/64	234	19/64	297	18/64	281	25/64	391
	Over 1,000	...	12/64	188	15/64	234	15/64	234	19/64	297	19/64	297	26/64	406
15,000	6–1,000	110	13/64	203	16/64	250	16/64	250	21/64	328	19/64	297	27/64	422
	Over 1,000	110	13/64	203	16/64	250	16/64	250	21/64	328	20/64	313	28/64	438
16,000	4 and larger	110	13/64	203	17/64	266	17/64	266	22/64	344				
17,000	4 and larger	115	14/64	219	18/64	281	18/64	281	23/64	359				
18,000	4 and larger	120	15/64	234	18/64	281	19/64	297						
19,000	4 and larger	125	15/64	234	19/64	297	20/64	313						
20,000	2 and larger	130	19/64	250	19/64	297	21/64	328						
21,000	2 and larger	135	16/64	250	20/64	313	22/64	344						
22,000	2 and larger	140	17/64	266	21/64	328	23/64	359						
23,000	2 and larger	145	17/64	266	22/64	344	24/64	375						
24,000	2 and larger	150	18/64	281	22/64	344	25/64	391						
25,000	2 and larger	155	18/64	281	23/64	359	26/64	406						
26,000	2 and larger	160	19/64	297	24/64	375	27/64	422						
27,000	2 and larger	160	19/64	297	25/64	391	28/64	438						
28,000	1 and larger	165	20/64	313	26/64	406	29/64	453						
29,000	1 and larger	165	21/64	328	27/64	422								
30,000	1 and larger	170	21/64	328	27/64	422								
31,000	1/0 and larger	175	23/64	344	28/64	438								
32,000	1/0 and larger	175	23/64	344	28/64	438								
33,000	1/0 and larger	180	23/64	359	29/64	453								
34,000	1/0 and larger	185	24/64	375	30/64	469								
35,000	1/0 and larger	190	24/64	375	31/64	484								
36,000	2/0 and larger	195	25/64	391										
37,000	2/0 and larger	200	26/64	406										
38,000	2/0 and larger	200	26/64	406										
39,000	2/0 and larger	205	27/64	422										
40,000	2/0 and larger	210	27/64	422										
41,000	3/0 and larger	215	28/64	438										
42,000	3/0 and larger	215	28/64	438										
43,000	3/0 and larger	220	29/64	453										
44,000	3/0 and larger	220	29/64	453										
45,000	3/0 and larger	225	30/64	469										
46,000	3/0 and larger	225	30/64	469										
47,000	4/0 and larger	235	31/64	484										
48,000	4/0 and larger	240	32/64	500										
49,000	4/0 and larger	245	32/64	500										

[a] For range of conductor sizes to which oil-filled thicknesses apply, see Secs. **117** and **118**.

Standard Insulation Thicknesses for Single-conductor Cable or Multiple-conductor Type H (Shielded) Cable (*Continued*)

Rated voltage, phase to phase	Size of conductor,[a] A.w.g., or 1,000 cir. mils	Paper			Rated voltage, phase to phase	Size of conductor,[a] A.w.g., or 1,000 cir. mils	Paper		
		Oil-filled[a]	Solid				Oil-filled[a]	Solid	
		Grounded neutral, mils	Grounded neutral				Grounded neutral, mils	Grounded neutral	
			In.	Mils				In.	Mils
50,000	4/0 and larger	245	33/64	516	75,000	.....	340		
51,000	4/0 and larger	250	34/64	531	80,000	.....	355		
52,000	4/0 and larger	250	34/64	531	85,000	.....	375		
53,000	250 and larger	255	35/64	547	90,000	.....	390		
54,000	250 and larger	255	36/64	563	95,000	.....	410		
55,000	250 and larger	260	36/64	563	100,000	.....	430		
56,000	250 and larger	265	37/64	578	105,000	.....	445		
57,000	250 and larger	270	37/64	578	110,000	.....	465		
58,000	300 and larger	275	38/64	594	115,000	.....	480		
59,000	300 and larger	275	38/64	594	120,000	.....	500		
60,000	300 and larger	280	39/64	609	125,000	.....	525		
61,000	300 and larger	285	39/64	609	130,000	.....	535		
62,000	300 and larger	290	40/64	625	135,000	.....	555		
63,000	300 and larger	290	40/64	625	138,000	.....	560		
64,000	300 and larger	295	41/64	641	140,000	.....	570		
65,000	350 and larger	295	42/64	656	145,000	.....	590		
66,000	350 and larger	300	42/64	656	150,000	.....	610		
67,000	350 and larger	305	43/64	672	155,000	.....	625		
68,000	350 and larger	310	44/64	688	160,000	.....	645		
69,000	350 and larger	315	44/64	688	161,000	.....	650		
70,000	.....	320			165,000	.....	660		
71,000	.....	320			230,000	.....	925		
72,000	.....	325							
73,000	.....	330							
74,000	.....	335							

[a] For range of conductor sizes to which oil-filled thicknesses apply, see Secs. **117** and **118.**

NOTES

OIL-FILLED PAPER CABLE.—A.E.I.C. and oil-filled cable manufacturers' insulation thicknesses, based on grounded-neutral, three-phase system, for single-conductor cables of 15,000 to 230,000 rated voltage, and three-conductor shielded cables of 15,000 to 69,000 rated voltage. For intermediate voltages the insulation thickness for the next higher voltage is recommended. All cables have an operating tolerance of 5 per cent above the rated voltage.

SOLID-TYPE PAPER CABLE.—A.E.I.C.—I.P.C.E.A. insulation thicknesses, based on grounded-neutral, three-phase system, for single-conductor cables of 0 to 69,000 rated voltage and multiconductor shielded cables of 10,000 to 35,000 rated voltage. Values given for ungrounded-neutral operation are from I.P.C.E.A. For intermediate voltages the insulation thickness for the next higher voltage is recommended. All cables have an operating tolerance of 5 per cent above the rated voltage, except those rated at 15,000 volts and below, which have no operating tolerance. Recommended minimum sector conductor sizes for three-conductor cable are 1 0. 2 0, 3 0, and 4 0 A.w.g., corresponding to voltage ranges of 10,000 to 20,000, 21,000 to 25,000, 26,000 to 30,000, and 31,000 to 35,000, respectively.

VARNISHED-CAMBRIC CABLE.—I.P.C.E.A. insulation thicknesses, based on three-phase system, for single-conductor cables and multiconductor shielded cables of 0 to 28,000 rated voltage with grounded neutral, and 0 to 17,000 rated voltage with ungrounded neutral. For intermediate voltages the insulation thickness for the next higher voltage is recommended. All cables have an operating tolerance of 5 per cent above the rated voltage, except those rated at 15,000 volts and below, which have no operating tolerance.

RUBBER CABLE.—I.P.C.E.A. insulation thicknesses, for all grades of compounds, based on grounded- and ungrounded-neutral, three-phase system, for single- and multiconductor shielded or unshielded cables. For intermediate voltages the insulation thickness for the next higher voltage is recommended.

117. Supplementary Table for Insulation Thicknesses for Single-conductor, Oil-filled Cable

(General Cable Corp.)

Voltage range	Size, A.w.g. or 1,000 cir. mils	Insulation thickness	Size, 1,000 cir. mils	Insulation thickness
15,000– 19,000	1/0– 750	As given in Table 116	751–2,500	125 mils
			Over 2,500	140 mils
20,000– 35,000	1/0–2,500		Over 2,500	Add 15 mils to values in Table 116
36,000– 74,000	2/0–2,500		Over 2,500	
75,000–110,000	3/0–2,500		Over 2,500	
115,000–155,000	4/0–2,500		Over 2,500	
160,000–165,000	250–2,500		Over 2,500	
230,000	750–2,500		Over 2,500	

118. Supplementary Table for Insulation Thicknesses for Three-conductor, Oil-filled Cable

(General Cable Corp.)

Voltage range	Size, A.w.g. or 1,000 cir. mils		Insulation thickness	Size, 1,000 cir. mils	Insulation thickness to values in Table 116
	Round	Sector			
15,000–34,000	1–600	1/0–600	As given in Table 116	601–850	Add 15 mils
				Over 850	Add 30 mils
34,500–41,000	1/0–600	2/0–600		601–850	Add 15 mils
				Over 850	Add 30 mils
42,000–60,000	1/0–750	2/0–750		751–850	Add 15 mils
				Over 850	Add 30 mils
61,000–69,000	2/0–750	3/0–750		751–850	Add 15 mils
				Over 850	Add 30 mils

119. Thickness of Insulation for Asbestos-insulated Conductors—600 Volts

(National Electrical Code)

Trade name	Type letter	Insulation	Thickness of insulation (dimensions in mils)					Outer covering
Asbestos	A	Asbestos	14				30	Without asbestos braid
			12–8				40	
Asbestos	AA	Asbestos	14				30	With asbestos braid
			12–8				30	
			6–2				40	
			1–4/0				60	
Asbestos	AI	Impregnated asbestos	14				30	Without asbestos braid
			12–8				40	
Asbestos	AIA	Impregnated asbestos				Solid	Stranded	With asbestos braid
			14			30	30	
			12–8			30	40	
			6–2			40	60	
			1–4/0			60	75	
			213–500			..	90	
			501–1,000			..	105	
Asbestos and varnished cambric	AVA and AVL	Impregnated asbestos and varnished cambric			VC	AVA asbestos	AVL asbestos	AVA-asbestos braid
			14–8 (solid only)		30	20	25	
				1st Asbestos	VC	AVA 2d asbestos	AVL 2d asbestos	AVL-asbestos braid and lead sheath
			14–8	10	30	15	25	
			6–2	15	30	20	25	
			1–4/0	20	30	30	30	
			213–500	25	40	40	40	
			501–1,000	30	40	40	40	
			1,001–2,000	30	50	50	50	
Asbestos and varnished cambric	AVB	Impregnated asbestos and varnished cambric				VC	Asbestos	Flame-retardant cotton braid (switchboard wiring)
			18–8			30	20	
			6–2			40	30	
			1–4/0			40	40	
				Asbestos		VC	2d Asbestos	Flame-retardant cotton braid
			14–8	10		30	15	
			6–2	15		30	20	
			1–4/0	20		30	30	
			213–500	25		40	40	
			501–1,000	30		40	40	
			1,001–2,000	30		50	50	

120. Thickness of Asbestos and Varnished-cambric Insulation for Single-conductor Cable—Over 600 Volts

(National Electrical Code)

Conductor size, A.w.g. or 1,000 cir. mils	1st wall asbestos	Varnished cambric					2d wall asbestos
	For voltages not exceeding						
	1,000–5,000	1,000	2,000	3,000	4,000	5,000	1,000–5,000
14–2	15	45	60	80	100	120	25
1–4/0	20	45	60	80	100	120	30
213–500	25	45	60	80	100	120	40
501–1,000	30	45	60	80	100	120	40
1,001–2,000	30	55	75	95	115	140	50

121. Thickness of Insulation for Slow-burning and Slow-burning Weatherproof Insulated Conductors

(National Electrical Code)

Trade name	Type letter	Insulation	Thickness of insulation	Outer covering
Slow-burning	SB	3 braids impregnated fire-retardant cotton thread	14–10.....$\frac{3}{64}$ 8–2.....$\frac{4}{64}$ 1–4/0.....$\frac{5}{64}$ 213–500.....$\frac{6}{64}$ 501–1,000...$\frac{7}{64}$ 1,001–2,000..$\frac{8}{64}$	Outer cover finished smooth and hard
Slow-burning weatherproof	SBW	2 layers impregnated cotton thread	14–10.....$\frac{3}{64}$ 8–2.....$\frac{4}{64}$ 1–4/0.....$\frac{5}{64}$ 213–500....$\frac{6}{64}$ 501–1,000...$\frac{7}{64}$ 1,001–2,000..$\frac{8}{64}$	Outer fire-retardant coating

122. Standard Insulation Thicknesses for Multiconductor Belted Cable

(General Cable Corp.)

Rated voltage, phase to phase	Size of conductor, A.w.g. or 1,000 cir. mils	Paper						Varnished cambric					
		Conductor		Belt				Conductor		Belt			
				Grounded neutral		Ungrounded neutral				Grounded neutral		Ungrounded neutral	
		In.	Mils	In.	Mils	In.	Mils	In.	Mils	In.	Mils	In.	Mils
600	14–9	....	...	....	..	....	...	3/64	47				
	8	4/64	63	2/64	31	2/64	31	3/64	47				
	7–2	4/64	63	2/64	31	2/64	31	4/64	63				
	1–4/0	4/64	63	2/64	31	2/64	31	5/64	78				
	213–500	5/64	78	2/64	31	2/64	31	6/64	94				
	501–1,000	5/64	78	2/64	31	2/64	31	6/64	94	2/64	31	2/64	31
	Over 1,000	5/64	78	2/64	31	2/64	31	7/64	109	2/64	31	2/64	31
1,000	14–9	....	...	....	..	....	...	3/64	63				
	8–2	4/64	63	2/64	31	2/64	31	4/64	63				
	1–4/0	4/64	63	2/64	31	2/64	31	5/64	78				
	213–500	5/64	78	2/64	31	2/64	31	6/64	94				
	501–1,000	5/64	78	2/64	31	3/64	31	6/64	94	2/64	31	2/64	31
	Over 1,000	5/64	78	2/64	31	2/64	31	7/64	109	2/64	31	2/64	31
2,000	12–9	....	...	....	..	....	...	5/64	78				
	8–2	5/64	78	2/64	31	2/64	31	5/64	78				
	1–4/0	5/64	78	2/64	31	2/64	31	6/64	94				
	213–500	5/64	78	3/64	47	3/64	47	6/64	94				
	501–1,000	5/64	78	3/64	47	3/64	47	6/64	94	2/64	31	2/64	31
	Over 1,000	5/64	78	3/64	47	3/64	47	7/64	109	2/64	31	2/64	31
3,000	10–9	....	...	....	..	....	...	5/64	78	2/64	31	2/64	31
	8–2	5/64	78	3/64	47	3/64	47	5/64	78	2/64	31	2/64	31
	1–500	5/64	78	3/64	47	3/64	47	6/64	94	2/64	31	2/64	31
	501–1,000	5/64	78	3/64	47	3/64	47	6/64	94	3/64	47	3/64	47
	Over 1,000	5/64	78	3/64	47	3/64	47	7/64	109	3/64	47	3/64	47
4,000	8–500	6/64	94	3/64	47	3/64	47	6/64	94	3/64	47	3/64	47
	501–1,000	6/64	94	3/64	47	3/64	47	6/64	94	4/64	63	4/64	63
	Over 1,000	6/64	94	3/64	47	3/64	47	7/64	109	4/64	63	4/64	63
5,000	8–4/0	6/64	94	4/64	63	4/64	63	6/64	94	4/64	63	4/64	63
	213–1,000	6/64	94	4/64	63	4/64	63	7/64	109	4/64	63	4/64	63
	Over 1,000	6/64	94	4/64	63	4/64	63	7/64	109	5/64	78	5/64	78
6,000	8–4/0	6/64	94	4/64	63	4/64	63	6/64	94	5/64	78	5/64	78
	Over 4/0	6/64	94	4/64	63	4/64	63	7/64	109	5/64	78	5/64	78
7,000	8 and larger	7/64	109	4/64	63	6/64	94	7/64	109	5/64	78	6/64	94
8,000	6 and larger	7/64	109	4/64	63	7/64	109	7/64	109	6/64	94	7/64	109

Standard Insulation Thicknesses for Multiconductor Belted Cable
(*Continued*)

Rated voltage, phase to phase	Size of conductor, A.w.g. or 1,000 cir. mils	Paper						Varnished cambric					
		Conductor		Belt				Conductor		Belt			
				Grounded neutral		Ungrounded neutral				Grounded neutral		Ungrounded neutral	
		In.	Mils	In.	Mils	In.	Mils	In.	Mils	In.	Mils	In.	Mils
9,000	6 and larger	8/64	125	4/64	63	8/64	125	8/64	125	6/64	94	8/64	125
10,000	6 and larger	8/64	125	4/64	63	8/64	125	9/64	141	6/64	94	9/64	141
11,000	6 and larger	8/64	125	5/64	78	8/64	125	10/64	156	6/64	94	10/64	156
12,000	6 and larger	9/64	141	5/64	78	9/64	141	10/64	156	7/64	109	10/64	156
13,000	6 and larger	9/64	141	5/64	78	9/64	141	11/64	172	7/64	109	11/64	172
14,000	6 and larger	10/64	156	5/64	78	10/64	156	12/64	188	7/64	109	12/64	188
15,000	6 and larger	10/64	156	5/64	78	10/64	156	13/64	203	7/64	109	13/64	203
16,000	4 and larger	....	...	....	..	....	...	14/64	219	7/64	109	14/64	219
17,000	4 and larger	....	...	....	..	....	...	14/64	219	7/64	109	14/64	219

NOTES

SOLID-TYPE PAPER CABLE.—A.E.I.C.—I.P.C.E.A. insulation thicknesses, based on ounded-neutral, three-phase system, for multiconductor belted cables. Values given r ungrounded-neutral operation are from I.P.C.E.A. For intermediate voltages the sulation thickness for the next higher voltage is recommended. Cables rated at ,000 volts and below have no operating tolerance with respect to operating voltage. ecommended minimum sector conductor size is 1/0 A.w.g.

VARNISHED-CAMBRIC CABLE.—I.P.C.E.A. insulation thicknesses, based on three-phase stem, for multiconductor belted cables. For intermediate voltages the insulation ickness for the next higher voltage is recommended. All cables have an operating lerance of 5 per cent above the rated voltage, except those rated at 15,000 volts and low, which have no operating tolerance.

RUBBER CABLES.—For multiconductor unshielded rubber-insulated cables the thicksses given in Sec. **116** apply.

123. Voltage Ranges and Shielding Practice for Insulated Cable

(General Electric Co.)

Class of insulation	Shielding (if any)	Finish	Single or multiple conductor	Voltage range		
				Recommended		Can furnish, max.
				Max.	Min.	
Paper						
Oil-filled	Nonshielded	Leaded	Single	230,000	60,000	230,000
	Shielded	Leaded	Multiple	75,000	35,000	75,000
Standard solid	Shielded	Leaded	Single	69,000	40,000	75,000
	Nonshielded	Leaded	Single	40,000	.....	75,000
	Shielded	Leaded	Multiple	35,000	10,000	45,000
	Belted	Leaded	Multiple	10,000	.....	25,000
Varnished-cambric						
Standard varnished-cambric insulation	Nonshielded	Leaded	Single	26,000	.....	26,000
	Nonshielded	Braided[a]	Single	7,500	.....	7,500
	Shielded	Braided[a]	Single	26,000	7,500	26,000
	Shielded	Leaded	Multiple	26,000	10,000	26,000
	Shielded	Braided[a]	Multiple	26,000	7,500	26,000
	Belted	Leaded	Multiple	10,000	.....	17,000
	Belted	Braided[a]	Multiple	7,500	.....	7,500

Class of insulation	Shielding (if any)	Finish	Single or multiple conductor	Voltage range		
				Recommended		Can furnish, max.
				Max.	Min.	
Asbestos						
Asbestos–varnished-cambric	Nonshielded	Leaded	Single	13,800	.....	13,800
	Nonshielded	Braided[a]	Single	13,800	.....	13,800
	Nonshielded	Leaded	Multiple	13,800	.....	13,800
	Nonshielded	Braided[a]	Multiple	13,800	.....	13,800
Felted-asbestos	Nonshielded	Braided[a]	Single	600	.....	600
Rubber						
Special compounds[b]	Nonshielded	Leaded	Single	15,000	.....	15,000
30 per cent A.S.T.M. Class AO compound	Nonshielded	Braided[a]	Single	6,000Y 3,500Δ	.....	6,000Y 3,500Δ
	Shielded	Braided[a]	Single	15,000	6,000Y 3,500Δ	15,000
	Shielded	Leaded	Multiple	15,000	10,000Y 6,000Δ	15,000
	Shielded	Braided[a]	Multiple	15,000	6,000Y 3,500Δ	15,000
	Nonshielded	Leaded	Multiple	10,000Y 6,000Δ	.....	10,000Y 6,000Δ
	Nonshielded	Braided[a]	Multiple	6,000Y 3,500Δ	.....	6,000Y 3,500Δ
20 or 25 per cent N.E. Code compound	Nonshielded	Leaded	Single	5,000	.....	5,000
	Nonshielded	Braided[a]	Single	3,000	.....	3,000
	Nonshielded	Leaded	Multiple	3,000	.....	3,000
	Nonshielded	Braided[a]	Multiple	3,000	.....	3,000

[a] Not mounted on insulators.

[b] Special compounds rated same as 30 per cent A.S.T.M. Class AO.

124. Recommended Cable Ratings for Series-lighting, Rubber-insulated Cable and Varnished-cambric-insulated Cable

(General Electric Co.)

Transformer ratings, kw.	Secondary circuit voltage at 6.6 amp.		Without protectors			With protectors		
	Open	Closed or loaded	Recommended voltage rating	Recommended insul. wall		Recommended voltage rating	Recommended insul. wall	
				Size, A.w.g.	Thickness, in.		Size, A.w.g.	Thickness, in.
1	225	152	600	8–4	4/64	600	8–4	4/64
2	430	303	600	8–4	4/64	600	8–4	4/64
3	660	454	1,000	8	4/64	600	8–4	4/64
				7–4	5/64			
5	1,080	757	2,000	8	5/64	1,000	8	4/64
				7–4	6/64		7–4	5/64
7.5	1,600	1,137	2,000	8	5/64	2,000	8	5/64
				7–4	6/64		7–4	6/64
10	2,090	1,515	3,000	8	7/64	2,000	8	5/64
				7–4	8/64		7–4	6/64
15	3,090	2,272	4,000	8–4	9/64	3,000	8	7/64
							7–4	8/64
20	4,115	3,030	5,000	8–4	19/64	4,000	8–4	9/64
25	5,110	3,787	6,000	8–4	19/64	4,000	8–4	9/64
30	6,130	4,545	7,000	8–4	11/64	5,000	8–4	10/64
40	8,260	6,060	9,000	8–4	13/64	7,000	8–4	11/64
50	10,350	7,580	11,000	8–4	15/64	8,000	8–4	12/64
60	12,400	9,100	13,000	[a]	17/64	10,000	[a]	14/64
70	14,500	10,600	15,000	[a]	19/64	11,000	[a]	15/64

[a] 8–4 for rubber-insulated.
6–4 for varnished-cambric-insulated.

125. Common Protective Coverings.—The more common protective covering combinations that are available are listed below, together with the general field of application of each. For each combination covering, the materials are listed in the order that they are applied in the manufacture of the cable.

Covering	Application
1. Single braid	*a.* General low-voltage use in dry or slightly moist locations for single-conductor, rubber-insulated cables No. 8 or smaller *b.* Varnished-cambric-insulated cables 1 in. or less in diameter *c.* All-asbestos-insulated cables
2. (*a*) Double braid or (*b*) rubberized tape-cotton braid (most common)	General low-voltage use in dry or slightly moist locations for all cables except those listed under 1 above

Types of braid employed for Nos. 1 and 2 coverings as follows:

Light cotton	Only on Code and intermediate-grade rubber-insulated cables
Standard cotton	Outer braid for rubber- and varnished-cambric-insulated cable for indoor service and installation in conduit
Heavy cotton	Outer braid for rubber- and varnished-cambric-insulated cable for outdoor or fairly rough service
Seine twine or hawser cord	Outer braid for rubber- and varnished-cambric-insulated cables subjected to rough service
Sisal cord or hemp	Outer braid for rubber- and varnished-cambric-insulated cables subjected to special rough service
Asbestos	Asbestos-insulated cables and rubber-insulated cables subjected to possible momentary flame
Glazed cotton, rayon, and silk	Small flexible cords for light-duty indoor installations
3. Rubberized tape, woven cover	Low-voltage control or small-sized power cables subjected to special rough service, tree wire
4. Rubber or synthetic jacket	Flexible power cables and for cables for direct burial in earth
5. Rubberized tape, lead sheath; or simply lead sheath	Any cable subjected to severe moisture conditions and ordinary mechanical strains
6. Jute, flat-band armor	Cables in dry locations subject to impact or abrasion
7. Jute, interlocking armor	Cables in dry locations similar to 6 but for greater protection against impact or abrasion
8. Rubberized tape, basket-weave armor	Cables in dry locations requiring compact and flexible mechanical protection of light weight
9. Jute, wire armor	Cable in dry locations subject to extreme tension or abrasion

10. Lead-sheathed cable, jute flat-band armor..... Same as 6 for cable subjected to moisture
11. Lead-sheathed cable, jute-interlocking armor..... Same as 7 for cable subjected to moisture
12. Lead-sheathed cable, jute wire armor Same as 9 for cable subjected to moisture
13. Lead-sheathed cable, basket-weave armor..... Same as 8 for cable subjected to moisture

126. The following additional coverings are employed over cable protective coverings 5, 6, 7, 8, 9, 10, 11, 12, and 13, listed above, in order to provide additional protection when subjected to acids, alkalies, corrosive vapors, electrolysis, etc.

1. Asphalt and one heavy cotton braid
2. Asphalt and two heavy cotton braids
3. Asphalt and one duck tape
4. Asphalt and two duck tapes
5. Asphalt and one jute serving
6. Asphalt and two jute servings
7. Asphalt, jute serving, heavy cotton braid
8. Asphalt, jute serving, duck tape
9. Asphalt, two self-vulcanizing tapes, duck tape
10. Asphalt, two self-vulcanizing tapes, heavy cotton braid
11. Asphalt-asbestos tape or braid

127. Common Saturants and Finishes for Braided Cables

Saturant	Finish	Characteristics
1. Asphalt	Wax (smooth black)	Moisture resisting, flame retarding, abrasion resisting
2. Asphalt	Mica-coated, stearine pitch	Moisture resisting; flame retarding; abrasion resisting. Better moisture resistance than 1 but not such good abrasion resistance. This saturant and finish are applied in two grades; MRFR for duct and conduit use and URC for outdoor aerial use (weatherproof)
3. Paint (slow-burning)	Paint slow-burning	High resistance to heat and flame, not moisture resistant
4. Asphalt or paint	Lacquer	Moisture resisting; oil and ozone resisting; resistance to some chemicals. Not abrasion resisting and therefore not recommended for installation in ducts, conduits, or casings
5. Varnish	Varnish	Moisture resisting, oil resisting, some resistance to abrasion

128. Minimum Standard Thicknesses for Braid Coverings

Diam. under braid, in.	Thickness of single braid, in.			
	Cotton braids			Asbestos
	Code	Standard	Heavy	
0–0.200	0.015	0.0163	0.020	0.045
0.201–0.300	0.017	0.0175	0.0223	0.045
0.301–0.350	0.017	0.0175	0.0258	0.045
0.351–0.600	0.020	0.0200	0.0258	0.050
0.601–0.800	0.020	0.0200	0.0316	0.050
0.801–1.000	0.025	0.0258	0.0316	0.050
1.001–1.500	0.025	0.0258	0.037	0.050
1.501–2.000	0.031	0.0316	0.0446	0.050
2.001–3.000	0.031	0.0316	0.0556	0.050

129. Minimum Standard Thicknesses of Lead Sheath

Diam. under lead sheath, in.	Min. thickness of sheath							
	Rubber-, varnished-cambric- or asbestos-insulated cable		Paper insulated					
			Single lead sheath				Double lead sheath (reinforced)	
			Solid type		Oil filled			
	In.	Mils	In.	Mils	In.	Mils	Inner sheath, mils	Outer sheath, mils
0–0.425	3/64	47	5/64	78	.....	...	95	95
0.426–0.600	4/64	63	5/64	78	.....	...	95	95
0.601–0.700	4/64	63	5.5/64	86	.....	...	95	95
0.701–0.900	5/64	78	5.5/64	86	.....	...	95	95
0.901–1.050	5/64	78	6/64	94	7/64	109	95	95
1.051–1.200	6/64	94	6/64	94	7/64	109	95	95
1.201–1.500	6/64	94	6.5/64	101	7/64	109	95	95
1.501–1.800	7/64	109	7/64	109	7.5/64	117	95	95
1.801–2.000	7/64	109	7.5/64	117	8/64	125	105	105
2.001–2.100	8/64	125	7.5/64	117	8/64	125	105	105
2.101–2.400	8/64	125	8/64	125	8.5/64	133	105	105
2.401–2.700	8/64	125	8.5/64	133	9/64	141	115	115
2.701–3.000	8/64	125	9/64	141	9.5/64	149	115	115
3.001–3.300	9/64	141	10/64	156	10/64	156	125	125
3.301–3.600	9/64	141	10.5/64	164	11/64	172	125	125
3.601 and over	9/64	141	11/64	172	11/64	172	125	125

130. Standard Thicknesses for Jute Serving as Protection over Lead Sheaths without Metallic Armor

Diam. over lead sheath, in.	Min. thickness of jute serving			
	One serving		Two servings	
	In.	Mils	In.	Mils
0–1.000	1/64	63	6/64	94
1.001–2.500	1/64	63	7/64	109
2.501 and larger.....	1/64	63	8/64	125

131. Standard Thicknesses of Fibrous Coverings over Lead Sheaths without Metallic Armor

Diam. over lead sheath, in.	Min. thickness of		
	Each tape, mils	Braid	
		In.	Mils
0–0.750	20	3/64	47
0.751–1.000	20	4/64	63
1.001–2.500	20	5/64	78
2.501 and larger.....	20	6/64	94

132. Standard Thicknesses of Jute Bedding for Armored Cables

Cable diam. under jute bedding, in.	Lead-sheathed cables				Nonleaded cables	
	Tape armored		Wire armored		Tape or wire armored	
	In.	Mils	In.	Mils	In.	Mils
0–0.450.....	3/64	31	3/64	47	5/64	78
0.451–0.750.....	3/64	47	3/64	47	5/64	78
0.751–1.000.....	3/64	47	4/64	63	6/64	94
1.001–2.500.....	4/64	63	5/64	78	7/64	109
2.501 and larger.....	4/64	63	6/64	94	8/64	125

Thickness of jute bedding for twin-flat constructions shall be that corresponding to the major core diameter.

133. Standard Dimensions for Flat-tape and Round-wire Steel Armor

Diam. of cable under jute bedding,[a] in.	Dimensions of armor			
	Flat tape		Round wire	
	Max. average width, in.	Min. average thickness, in.	Min. size, B.w.g.	Diam., in.
0–0.450	0.75	0.020	12	0.109
451–0.750	1.00	0.020	12	0.109
751–1.000	1.00	0.020	10	0.134
001–1.400	1.25	0.030	8	0.165
401–1.700	1.50	0.030	8	0.165
701–2.000	1.50	0.030	6	0.203
001–2.500	2.00	0.030	6	0.203
501 and larger	2.00	0.030	4	0.238

[a] For tape armor on twin-flat constructions, dimensions are based on diameter of ajor axis. Tape armor is usually supplied with two tapes applied in same direction, th outer tape approximately centered over spaces between convolutions of inner tape, ch spaces not to exceed 10 per cent of width of tape.

Special requirements for wire-armored dredger cables:

iam. under jute bedding, in.	0–1.700	1.701–2.500	2.501 and larger
in. size armor wire, B.w.g.	12	10	8

134. Standard Dimensions for Interlocking Steel-tape Armor

Diam. over lead or braid		Dimensions of tape before forming		
			Min. average thickness, in.	
Vith jute bedding, in.	Without jute bedding, in.	Max. width, in.	Steel or bronze	Aluminum, brass, or zinc
0–0.388	0–0.450	0.375	0.020	0.25
389–0.656	0.451–0.750	0.500	0.020	0.25
557–0.906	0.751–1.000	0.750	0.020	0.25
907–1.275	1.001–1.400	0.875	0.020	0.25
276–1.875	1.401–2.000	1.250	0.025	0.30
876 and larger	2.001 and larger	2.000	0.025	0.30

135. Minimum Bending Radii for Installation of Rubber- and Varnished-cambric-insulated Cables[a]

Thickness of conductor insulation, in.	Min. bending radii as a multiple of cable over-all diam.	
	Up to 500,000 cir. mils	500,000 cir. mils and over
Varnished cambric		
Up to 3/64	5	5
3/64–13/64	5	6
13/64–29/64	6	7
21/64 and over	7	7
Rubber		
Up to 3/64	3	4
3/64–13/64	4	5
13/64–29/64	5	6
21/64 and over	6	6

136. Minimum Bending Radii for Installation of Paper-insulated Cables[a]

Single-conductor and Nonbelted Cables

Conductor insulation thickness, in.	Outside diameter of cable, in.		
	0–0.750	0.751–1.500	Over 1.500
	Minimum bending radii as a multiple of cable diam.		
19/64 and less	5	6	7
13/64–29/64	6	6½	7
Over 29/64	6½	7	7

Multiconductor Belted Cables

Outside diam. in.	Min. bending radii as a multiple of cable diam.
1.000 and less	5
1.001–1.500	6
Over 1.500	7

[a] For method of computing minimum allowable bending radius see example on next page.

Example.—Determine the minimum allowable bending radius for a 4/0 single-conductor braided cable insulated with $^{11}/_{64}$ in. of varnished cambric.

Solution.—From Tables 117 to 122 a thickness of $^{11}/_{64}$ in. would be used on 8,000-volt cable. From Table 147 the over-all diameter of an 8,000-volt braided cable is 0.957 in. From the table above, the minimum allowable bending radius is 5 times the over-all diameter of the cable. Therefore the minimum allowable bending radius = 5 × 0.957 = 4.785 in.

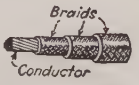
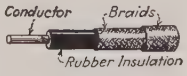
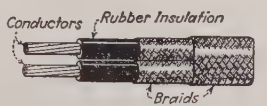
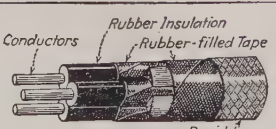
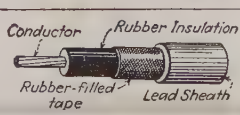
137. Standard Armor-wire Sizes for Vertical-riser, Borehole, and Dredge Cable

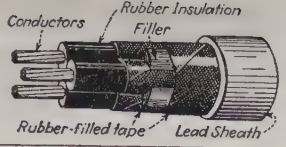
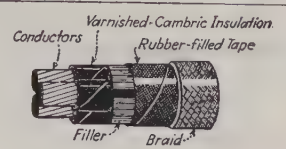
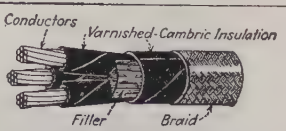
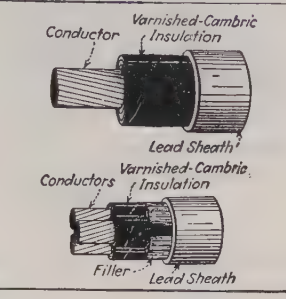
Diam. under jute bedding, in.	Min. size of armor wire, B.w.g.		
	Vertical riser	Borehole	Dredge
0–0.750	12	12	12
0.751–1.000	12	10	12
1.001–1.700	10	8	12
1.701–2.500	8	6	10
2.501 and larger	6	4	8

138. Standard Wire Servings over Armor Wire for Borehole and Vertical-riser Cables

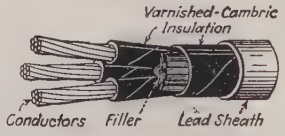
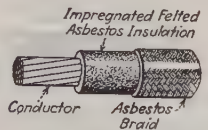
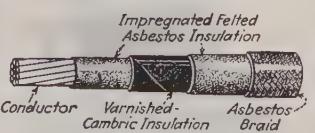
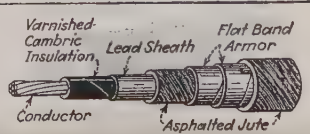
Diam. over armor wire, in.	Max. band spacing, ft.	Length of band, in.
0–1.500	50	3
1.501–2.500	35	4
2.501 and larger	25	4

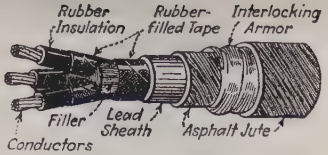
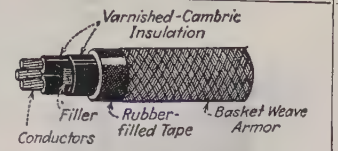
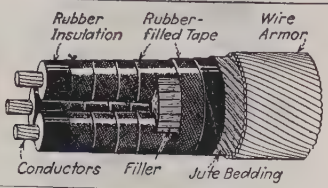
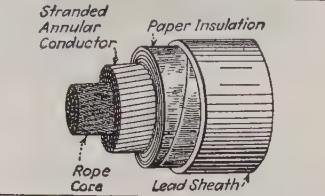
139. Common Cable Assemblies

Type	Illustration	Description in sec.	Data in tables	Explanation
		General-purpose Power Cables		
1. Covered wires (non-insulated): (*a*) weatherproof, (*b*) slow-burning, (*c*) slow-burning, weatherproof.		11–14	140–143	Copper is most common conductor material, but copperweld, bronze, composite copper-copperweld, all aluminum, or steel-reinforced aluminum may be used. Conductor covered with two or three cotton braids impregnated with weather- or heat-resisting compounds
2. Rubber-insulated, single-conductor, braid-covered cable.		27, 54	144	Solid or stranded copper conductor. Rubber insulation may be any one of available compounds (Secs. **27** and **28**). For number and type of braids see Sec. **125**
3. Rubber-insulated, two-conductor, braid-covered cable.		27, 54	145, 146	Refer to explanation under item 2. Two-conductor cables are made with twin-flat construction as illustrated and also in round construction. Covering for smaller sizes consists, as illustrated, of braid over each conductor and an over-all braid. Covering for larger sizes is similar to item 4 with tape over each conductor and over-all covering of tape and braid
4. Rubber-insulated, three-conductor, braid-covered cable.		27, 54	146	Refer to explanation under item 2. Covering over individual conductors is generally braid for smaller sizes and tape for the larger sizes. Over-all covering is generally tape and braid
5. Rubber-insulated, single-conductor, lead-covered cable.		27, 46–48, 54	144	Solid or stranded copper conductor. Rubber insulation may be any one of available types (see Secs. **27** and **28**). Covering consists of tape and lead sheath

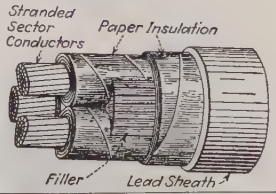
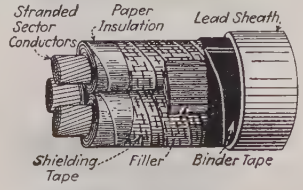
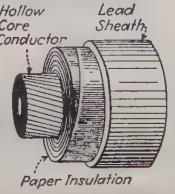
6. Rubber-insulated multiconductor, lead-covered cable.		27, 46–48, 54	145, 146	Two-conductor cable may be obtained in twin-flat and round construction. The covering for twin-flat, construction consists of tape over each conductor with an over-all lead sheath. The most common assembly for all other multiconductor cables is a tape over each conductor with an over-all covering of tape and lead sheath, as illustrated
7. Varnished-cambric-insulated, braid-covered cable, without shielding or belting.		30, 54	147–149	Solid or stranded copper conductor (see Table 81). Insulation is either standard black or heat resisting. For multiconductor cables, no covering is employed over insulation of individual conductors. For number and type of braids for single-conductor cable and for outer covering of multiconductor cables see Sec. **125**. Two-conductor cables are of round construction
8. Varnished-cambric-insulated, belted, braid-covered cable.		30, 54	149	Solid or stranded copper conductor (see Table 81). Insulation is either standard black or heat resisting. For number and type of braids see Sec. **125**.
9. Varnished-cambric-insulated, lead-covered cable, without shielding or belting.		30, 46–48, 54	147–149	Solid or stranded copper conductor (see Sec. **81**). Insulation is either standard black or heat resisting. Lead sheath applied directly over insulation for single-conductor cable. No binder tape used with multiconductor cable

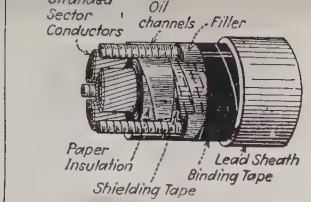
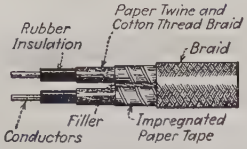
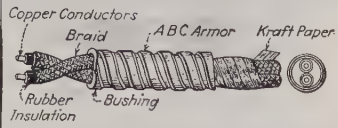
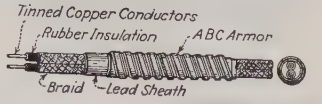
Common Cable Assemblies (*Continued*)

Type	Illustration	Description in sec.	Data in tables	Explanation
10. Varnished-cambric, lead-covered, belted cable.		30, 46–48, 54	149	Solid or stranded copper conductor (see Sec. **81**). Insulation is either standard black or heat resisting
11. All-asbestos-insulated cable.		31, 54	157	Solid or stranded copper conductor. Felted asbestos insulation saturated with flame- and heat-resisting compound or flame-, heat-, and moisture-resisting compound. Covering consists of asbestos braid or lead sheath. Majority of cables are single conductor, but multiconductor cables can be obtained
12. Asbestos varnished-cambric-insulated cable.		31, 54	158	Solid or stranded copper conductor. Insulation consists of a layer of varnished cambric between two layers of impregnated felted asbestos. Covering consists of asbestos braid or lead sheath. Majority of cables are single conductor, but multiconductor cables can be obtained
13. Flat-band armored cable.		49	.....	Jute and flat-band armor alone or combined with any one of the additional protective coverings Nos. 1 to 11 in Table 126 may be employed as protective coverings directly over the insulated cable or over a lead-sheathed cable

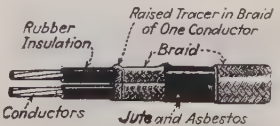
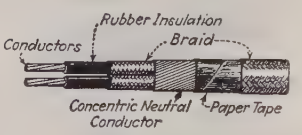
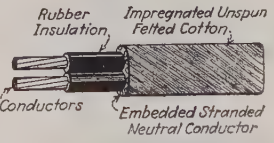
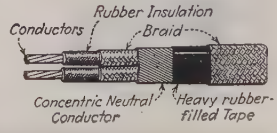
14. Interlocking armored cable.		50	.....	Jute and interlocking armor alone or combined with any one of the additional protective coverings Nos. 1 to 11 in Table 126 may be employed as protective coverings directly over the insulated cable or over a lead-sheathed cable
15. Basket-weave armored cable.		52	.....	Basket-weave armor alone or combined with any one of the additional protective coverings Nos. 1 to 11 in Table 126 may be employed as protective covering over braided, rubber-jacketed, or lead-sheathed cable
16. Wire-armored cable.		51	.....	Jute and wire armor alone or combined with any one of the additional protective coverings Nos. 1 to 11 in Table 126 may be employed as protective covering directly over insulated cable or over a lead-sheathed cable
17. Solid-type, paper-insulated, single-conductor cable.		29, 46–48	149–153	Solid or stranded copper conductor (see Table 81). Illustration shows a cable with an annular concentric-stranded conductor with rope core. Lead sheath is applied directly over insulation

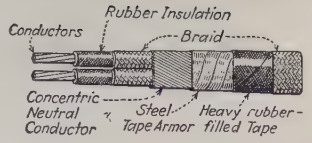
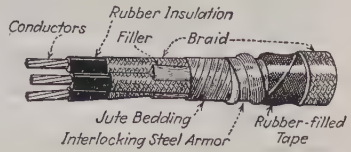
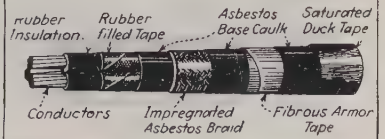
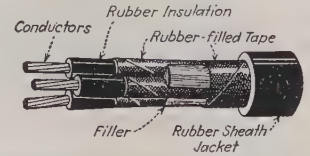
Common Cable Assemblies (*Continued*)

Type	Illustration	Description in sec.	Data in tables	Explanation
18. Solid-type, paper-insulated, three-conductor, belted cable.		29, 46–48	154	Solid or stranded copper conductor (see Table 81). Illustration shows a cable with compack-sector stranded conductors. Lead sheath is applied directly over insulation
19. Solid-type, paper-insulated, three-conductor, shielded (Type H) cable.		29, 46–48	155	Stranded copper conductor (see Table 81). A shielding tape is applied around each conductor. The assembly is bound together with an interlocking paper tape covered with a bronze binder tape. Lead sheath is applied directly over the binder tape
20. Oil-filled, paper-insulated, single-conductor cable.		24, 46–48	155	Hollow-core stranded copper conductor. Oil channel is provided by hollow core of conductor. Lead sheath applied directly over insulation

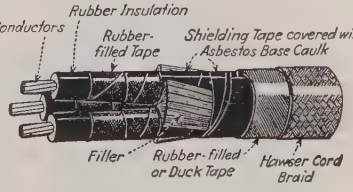
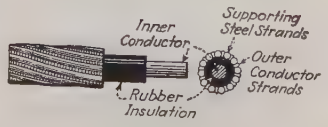
21. Oil-filled, paper-insulated, three-conductor, shielded cable (Type H).		24, 46–48	156	Stranded copper conductor. General construction same as for solid-type, paper-insulated Cable 19 except that three oil channels are provided by three springs laid in the spaces between the conductors
	Special Building Wires			
22. Nonmetallic-sheathed building cable.		55	159	Solid or stranded copper conductors. Rubber or thermoplastic insulation. Each conductor protected with a braid of paper twine with cotton threads and a layer of impregnated paper tape. Over-all protection of a cotton braid. Made in two-, three-, and four-conductor assemblies
23. Armored cable, Type AC.		56	161–162	Solid or stranded copper conductors. Rubber or thermoplastic insulation. Each conductor protected with a cotton braid. Over-all protection of paper tape and flexible steel armor. Made in one-, two-, three-, and four-conductor assemblies
24. Armored cable, Type ACL.		56	160	Same as item 23 except that over-all protection consists of lead sheath covered with flexible steel armor

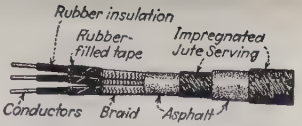
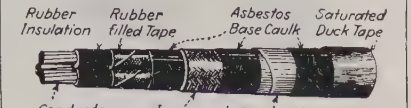
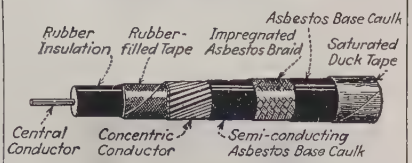
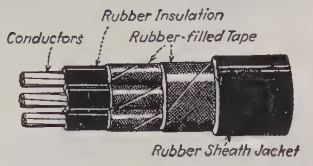
Common Cable Assemblies (*Continued*)

Type	Illustration	Description in sec.	Data in tables	Explanation
		Service Cables		
25 Service-drop cable (non-tamperproof type).		58	.....	Solid or stranded copper conductors. Rubber or thermoplastic insulation. Each conductor protected with standard cotton braid. Over-all protection of asbestos-base calk and heavy cotton braid. Available in two- and three-conductor assemblies
26. Service-drop cable, Type SD (tamperproof type).		58	.....	Solid or stranded copper conductors. Rubber or thermoplastic insulation on ungrounded conductors. Ungrounded conductors covered with cotton braid. Neutral conductor uninsulated and concentrically wound over other conductors. Over-all protection of paper tape and heavy cotton braid. Available in two- and three-conductor assemblies
27. Service-drop cable, Type SD (tamperproof type).		58	.....	Solid or stranded copper conductors. Rubber or thermoplastic insulation on ungrounded conductors, with no other covering. Over-all covering of unspun, felted, impregnated cotton. Neutral conductors concentric-wound and embedded in outer covering of cable
28. Service-entrance cable, Type SE (tamperproof type).		58	.....	Similar in general construction to item 26 but of tougher and heavier construction. Over-all protection of heavy rubberized cloth tape and heavy cotton braid

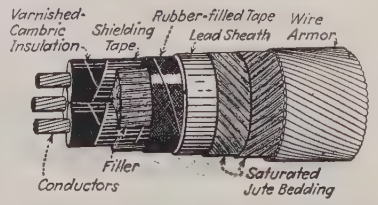
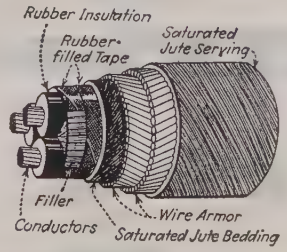
29. Armored service-entrance cable, Type ASE (tamperproof type).		58	.....	Solid or stranded copper conductors. Rubber or thermoplastic insulation on ungrounded conductors. Ungrounded conductors protected with cotton braid. Neutral conductor uninsulated and concentrically wound over other conductors. Over-all protection of flat steel tape, heavy rubberized cloth tape, and heavy cotton braid. Available in two- and three-conductor assemblies
30. Underground service-entrance cable, Type USE, metallic armor (also comes under Type ASE cable).		58	.....	Stranded copper conductors. All conductors rubber or thermoplastic insulated and protected with standard cotton braid. Over-all protection of asbestos-base calk or jute bedding, interlocking steel tape, rubberized cloth tape, and heavy cotton braid. Available in two- and three-conductor assemblies
31. Underground service-entrance cable, Type USE, nonmetallic armor.		58	.....	Solid or stranded copper conductors. Conductors rubber or thermoplastic insulated and protected with rubberized cloth tape. Over-all protection of asbestos-base calk, asbestos braid, asbestos-base calk, fibrous armor tape, asbestos-base calk and saturated duck tape. Also made with concentric-wound uninsulated neutral conductor. Available in two- and three-conductor assemblies
32. Underground service-entrance cable, Type USE, rubber-sheath armored.		58	.....	Solid or stranded copper conductors. Conductors rubber or thermoplastic insulated and protected with rubberized cloth tape. Over-all protection of rubberized cloth tape and rubber-sheath jacket. Also made with uninsulated neutral conductor covered with cotton braid. Available in one-, two-, and three-conductor assemblies

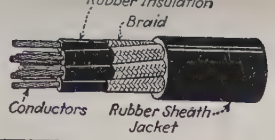
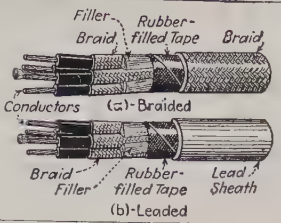
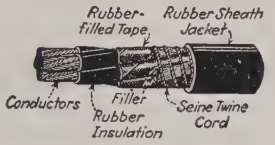
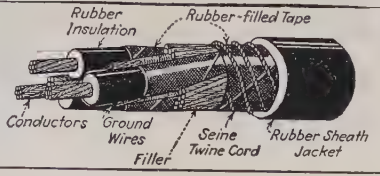
Common Cable Assemblies (*Continued*)

Type	Illustration	Description in sec.	Data in tables	Explanation
		Multiconductor Aerial Cables		
33. Nonleaded, shielded aerial cable.		59	.....	Solid or stranded copper conductors. Conductors may be rubber or varnished-cambric insulated and covered with rubberized cloth tape. Shielding tape over protection of each individual conductor. Over-all protection of shielding tape, rubberized cloth or duck tape, and outer seine-twine or hawser-cord braid
34. Self-supporting aerial cable.		59	.....	Solid or stranded copper conductors. Central conductor rubber or varnished-cambric insulated. Outer covering of interlocked steel and copper or aluminum wires applied directly over insulation. The copper wires of the covering provide a bare neutral conductor
		Power Cables for Direct Burial in Earth		
35. Leaded with metallic armor.	See figures for items No. 13 and 14.	60	.....	Solid or stranded copper conductors. Rubber insulation generally employed but varnished cambric or paper may be used. Available in two- and three-conductor assemblies. Armor may be flat band or interlocking. Any one of coverings 1 to 11 in Table 126 may be used over the armor

36. Nonmetallic, jute-and-asphalt armored cable.		60	.....	Solid or stranded copper conductors. Rubber insulation. Rubberized cloth tape and cotton braid over insulation of each conductor. Over-all armor of alternate layers of asphalt and impregnated-jute serving. Available in one-, two-, and three-conductor assemblies
37. Nonmetallic Trenchlay cable (General Cable Corp.).	 	60	.....	Solid or stranded copper conductors. Rubber insulation. Rubberized cloth tape over each insulated conductor. Over-all armor of asbestos-base calk, impregnated asbestos braid, asbestos-base calk, treated fibrous tape, asbestos-base calk, and presaturated heavy duck tape. Available in one-, two- and three-conductor assemblies. Available with all conductors insulated or with concentric-wound uninsulated neutral conductor
38. Nonmetallic, rubber-jacketed cable.		60	.....	Solid or stranded copper conductors. Rubber insulation. Rubberized cloth over insulation of each conductor. (Sometimes omitted in single-conductor cables.) Over-all covering of rubberized cloth binder tape and rubber jacket. Single-conductor cables also made with one rubber sheath directly over conductors, which serves as both insulation and jacket. Cables also available with a rubber jacket vulcanized to an outer synthetic jacket and covered with duck tape. Available in one-, two-, and three-conductor assemblies

Common Cable Assemblies (*Continued*)

Type	Illustration	Description in sec.	Data in tables	Explanation
		Borehole Cable		
39. Borehole or mine-shaft cable.		64	.....	Stranded copper conductors. Rubber or varnished-cambric insulation. Leaded or nonleaded. Over-all armor of jute and wire armor. Similar cables used for vertical risers in tall buildings
		Submarine Cables		
40. Nonleaded submarine cable.		65	.....	Stranded copper conductors. Rubber insulation. Over-all armor of jute, wire armor, and jute. Details of construction vary with requirements of installation

41. Rubber-sheathed control cable.		66	.....	Construction similar to item 42 except that over-all covering consists of rubber jacket
42. Braided or leaded control cable.		66	.....	Solid or stranded copper conductors. Rubber insulation generally employed, but varnished cambric may be used. Felted asbestos insulation used for high-temperature locations. Braid over each conductor and over-all covering of rubberized tape with outer braid or lead sheath. For high-temperature locations, outer covering of asbestos braid
	Portable Power Cables			
43. Portable power cables (low-voltage service).		70	.....	Especially flexible stranded copper conductors. High-grade rubber insulation (generally 40 per cent). Insulation of each conductor covered with cotton braid or rubberized tape. Over-all protection of rubber jacket, heavy cotton braid, seine-twine braid, loom sheath, or jute-and-wire armor. Ground wires may be included in cable assembly. Available in one-, two-, three-, and four-conductor assemblies. Two-conductor cables may be of twin-flat, round, or concentric construction
44. Portable power cables (high-voltage service).		70	.....	Similar in general construction to item 43 but with heavier walls of insulation and jacket. For voltages above 2,500, shielding is recommended

140. All-aluminum Weatherproof Covered Wire
(Aluminum Co. of America)

Aluminum, size, cir. mils or A.w.g.	Copper equivalent cir. mils or A.w.g.	Double-braid weatherproof			Triple-braid weatherproof		
		Diam., in.	Weight, lb. per 1,000 ft.	Weight, lb. per mile	Diam., in.	Weight, lb. per 1,000 ft.	Weight, lb. per mile
1,590,000	1,000,000	1.803	1,947	10,280	1.973	2,204	11,637
1,510,500	950,000	1.768	1,862	9,828	1.938	2,114	11,159
1,431,000	900,000	1.726	1,775	9,372	1.895	2,020	10,665
1,351,500	850,000	1.686	1,688	8,914	1.852	1,923	10,154
1,272,000	800,000	1.645	1,601	8,451	1.808	1,827	9,644
1,192,500	750,000	1.602	1,513	7,988	1.762	1,728	9,123
1,113,000	700,000	1.558	1,424	7,520	1.718	1,633	8,624
1,033,500	650,000	1.466	1,282	6,768	1.619	1,472	7,771
954,000	600,000	1.416	1,192	6,294	1.566	1,372	7,244
874,500	550,000	1.365	1,103	5,822	1.512	1,273	6,719
795,000	500,000	1.310	1,012	5,343	1.452	1,169	6,172
750,000	472,000	1.277	959	5,062	1.416	1,109	5,854
715,500	450,000	1.250	918	4,849	1.389	1,064	5,620
636,000	400,000	1.188	825	4,355	1.322	960	5,068
556,500	350,000	1.120	731	3,860	1.245	850	4,489
500,000	314,500	1.070	664	3,507	1.191	773	4,082
477,000	300,000	1.047	635.6	3,356	1.168	742.6	3,921
397,500	250,000	0.968	539.0	2,845	1.081	631.0	3,331
336,400	4/0	0.866	438.7	2,316	0.948	497.7	2,628
300,000	188,800	0.823	394.5	2,083	0.903	449.5	2,373
266,800	3/0	0.778	353.1	1,864	0.854	404.1	2,133
4/0	2/0	0.700	284.6	1,502	0.776	330.1	1,743
3/0	1/0	0.630	229.7	1,212	0.700	266.7	1,408
2/0	1	0.566	184.3	973	0.633	216.3	1,142
1/0	2	0.498	143.6	758	0.570	174.5	921
1	3	0.428	108.4	572	0.488	130.4	688
2	4	0.390	88.8	469	0.460	112.7	595
3	5	0.358	73.3	387	0.424	94.2	498
4	6	0.328	60.5	320	0.398	81.0	428

141. Properties of Weatherproof and Slow-burning Copper Wire and Cable (General Cable Co.)

Size B. & S. and cir. mils	Weatherproof				Slow-burning		
	Approx. weight, lb. per 1,000 ft.		Approx. over-all diam., in.		Approx. weight, lb. per 1,000 ft.		Approx. over-all diam., in. Type SB, Type SBW
	Type WP triple braid	Double braid	Type WP triple braid	Double braid	Type SB white finish	Type SBW, weather-proof black finish	
	Solid wire				Solid wire		
4/0	767	723	0.781	0.610	925	862	0.7500
3/0	629	587	0.735	0.560	760	710	0.7031
2/0	502	467	0.610	0.515	600	562	0.5781
1/0	407	377	0.563	0.470	495	462	0.5312
1	316	294	0.500	0.405	365	340	0.4687
2	260	239	0.478	0.374	320	280	0.4375
4	164	151	0.422	0.320	220	190	0.3750
6	112	100	0.391	0.278	160	127	0.3125
8	75	66	0.344	0.245	100	85	0.2656
10	53	46	0.312	0.197	80	60	0.2500
12	35	30	0.266	0.172	55	42	0.2187
14	25	20	0.250	0.155	40	30	0.1875
16	14	16	0.219	0.142	30	24	0.1562
18	12	12	0.187	.....	24	19	0.1250
20	11	9	0.156				
	Stranded wire or cable				Stranded wire or cable		
2,000,000	7,008	6,690	2.141	1.844	7,800	7,300	2.091
1,750,000	6.193	5,894	2.036	1.740	6,900	6,550	1.986
1,500,000	5,380	5,098	1.922	1.624	6,000	5,675	1.872
1,250,000	4,508	4,264	1.799	1.500	5,000	4,780	1.748
1,000,000	3,674	3,456	1.656	1.365	3,980	3,860	1.609
900,000	3,332	3,127	1.610	1.310	3,640	3,520	1.563
800,000	2,992	2,799	1.563	1.243	3,280	3,180	1.516
750,000	2,822	2,635	.....	1.210	3,100	3,000	
700,000	2,650	2,471	1.468	1.177	2,920	2,820	1.422
600,000	2,235	2,093	1.328	1.105	2,460	2,350	1.281
500,000	1,894	1,765	1.250	1.027	2,080	1,990	1.203
450,000	1,724	1,601	1.188	0.984	1,900	1,820	1.141
400,000	1,553	1,436	1.141	0.940	1,700	1,650	1.094
350,000	1,345	1,248	1.000	0.894	1,500	1,440	0.969
300,000	1,174	1,083	0.968	0.846	1,310	1,270	0.938
250,000	985	907	0.906	0.780	1,120	1,060	0.875
4/0	810	745	0.860	0.708	960	900	0.828
3/0	653	604	0.796	0.648	785	735	0.766
2/0	522	482	0.672	0.590	625	583	0.641
1/0	424	388	0.610	0.555	510	480	0.578
1	328	303	0.547	0.470	380	355	0.516
2	270	246	0.515	0.415	335	290	0.484
4	170	155	0.437	0.353	230	195	0.422
6	115	103	0.344	0.305	165	132	0.344
8	78	68	0.281	0.270	105	87	0.281

142. Aluminum Cable, Steel Reinforced, Double Braid, Weatherproof Covered

(Aluminum Co. of America)

A.C.S.R., size, B. & S. or A.w.g.	Copper equiv., B. & S. or A.w.g.	Stranding number and diam. of strands, in.		Diam., in.	Weight, lb. per 1,000 ft.				Percentage of total wt.		
		Alum.	Steel		Total	Alum.	Steel	Insulation	Alum.	Steel	Insulation
4/0	2/0	6/0.1878	1/0.1878	0.744	393.1	197.6	94.5	101.0	50.3	24.0	25.7
3/0	1/0	6/0.1672	1/0.1672	0.665	312.1	156.7	74.9	80.5	50.2	24.0	25.8
2/0	1	6/0.1490	1/0.1490	0.589	246.2	124.3	59.4	62.5	50.5	24.1	25.4
1/0	2	6/0.1327	1/0.1327	0.528	196.6	98.5	47.1	51.0	50.1	24.0	25.9
1	3	6/0.1182	1/0.1182	0.455	149.9	78.1	37.4	34.4	52.1	24.9	23.0
2	4	7/0.0974	1/0.1299	0.423	139.7	62.0	45.2	32.5	44.4	32.4	23.2
2	4	6/0.1052	1/0.1052	0.414	122.9	62.0	29.6	31.3	50.4	24.1	25.5
3	5	6/0.0937	1/0.0937	0.379	100.1	49.2	23.5	27.4	49.2	23.5	27.3
4	6	7/0.0772	1/0.1029	0.353	92.1	39.0	28.4	24.7	42.3	30.8	26.9
4	6	6/0.0834	1/0.0834	0.346	81.9	39.0	18.6	24.3	47.6	22.7	29.7
5	7	6/0.0743	1/0.0743	0.319	68.3	30.9	14.8	22.6	45.2	21.6	33.2
6	8	6/0.0661	1/0.0661	0.294	56.2	24.5	11.7	20.0	43.6	20.8	35.6
7	9	6/0.0589	1/0.0589	0.273	47.1	19.4	9.3	18.4	41.2	19.7	39.1
8	10	6/0.0525	1/0.0525	0.252	39.1	15.4	7.4	16.3	39.4	18.9	41.7

143. Aluminum Cable, Steel Reinforced, Triple Braid, Weatherproof Covered

(Aluminum Co. of America)

A.C.S.R., size, B. & S. or A.w.g.	Copper equiv., B. & S. or A.w.g.	Stranding number and diam. of strands, in.		Diam., in.	Weight, lb. per 1,000 ft.				Percentage of total wt.		
		Alum.	Steel		Total	Alum.	Steel	Insulation	Alum.	Steel	Insulation
4/0	2/0	6/0.1878	1/0.1878	0.824	434.1	197.6	94.5	142.0	45.5	21.8	32.7
3/0	1/0	6/0.1672	1/0.1672	0.749	352.6	156.7	74.9	121.0	44.4	21.2	34.4
2/0	1	6/0.1490	1/0.1490	0.660	283.7	124.3	59.4	100.0	43.8	20.9	35.3
1/0	2	6/0.1327	1/0.1327	0.606	227.6	98.5	47.1	82.0	43.3	20.7	36.0
1	3	6/0.1182	1/0.1182	0.515	170.0	78.1	37.4	54.5	45.9	22.0	32.1
2	4	7/0.0974	1/0.1299	0.493	160.4	62.0	45.2	53.2	38.6	28.2	33.2
2	4	6/0.1052	1/0.1052	0.484	144.3	62.0	29.6	52.7	43.0	20.5	36.5
3	5	6/0.0937	1/0.0937	0.445	119.2	49.2	23.5	46.5	41.3	19.7	39.0
4	6	7/0.0772	1/0.1029	0.423	111.4	39.0	28.4	44.0	35.0	25.5	39.7
4	6	6/0.0834	1/0.0834	0.416	101.1	39.0	18.6	43.5	38.6	18.4	43.0
5	7	6/0.0743	1/0.0743	0.379	82.7	30.9	14.8	37.0	37.3	17.9	44.8
6	8	6/0.0661	1/0.0661	0.353	69.7	24.5	11.7	33.5	35.2	16.8	48.0
7	9	6/0.0589	1/0.0589	0.331	59.4	19.4	9.3	30.7	32.6	15.7	51.7
8	10	6/0.0525	1/0.0525	0.310	51.2	15.4	7.4	28.4	30.1	14.5	55.4

144. Dimensions and Weights of Solid and Concentric-stranded, Rubber-insulated, Single-conductor, Braided and Leaded Cables

(General Cable Corp.)

Size, A.w.g. or cir. mils	Tape and braid covered						Lead sheathed					
	Over-all diam., in.			Wt., lb. per 1,000 ft.			Over-all diam., in.			Wt., lb. per 1,000 ft.		
	600 volts	2,001–3,000 volts	4,001–5,000 volts	600 volts	2,001–3,000 volts	4,001–5,000 volts	600 volts	2,001–3,000 volts	4,001–5,000 volts	600 volts	2,001–3,000 volts	4,001–5,000 volts
Solid												
14	0.22	....	....	29	.....	.....	0.25	....	....	135		
12	0.24	....	....	38	.....	.....	0.27	....	....	153		
10	0.26	0.45	0.55	54	117	164	0.32	0.45	0.57	260	374	626
8	0.32	0.48	0.57	85	144	194	0.38	0.47	0.60	320	419	679
6	0.36	0.51	0.57	120	189	225	0.45	0.57	0.63	520	660	754
4	....	....	....	.....	.....	.....	0.51	....	....	620		
Stranded												
14	0.23	....	....	30	.....	.....	0.25	....	....	142		
12	0.25	....	....	40	.....	.....	0.27	....	....	161		
10	0.27	....	....	56	.....	.....	0.32	....	....	274		
8	0.33	....	....	90	.....	.....	0.38	....	....	337		
6	0.38	0.53	0.59	126	202	239	0.47	0.59	0.65	548	694	788
4	0.45	0.58	0.64	190	269	309	0.52	0.64	0.70	655	805	905
2	0.51	0.64	0.70	278	369	414	0.58	0.70	0.76	770	962	1,064
1	0.59	0.68	0.74	364	442	483	0.64	0.74	0.80	931	1,071	1,171
1/0	0.63	0.72	0.80	443	520	588	0.68	0.78	0.87	1,060	1,187	1,504
2/0	0.67	0.76	0.84	540	623	695	0.73	0.82	0.92	1,210	1,332	1,664
3/0	0.73	0.83	0.89	663	771	830	0.78	0.91	0.97	1,370	1,726	1,858
4/0	0.78	0.89	0.95	814	932	994	0.84	0.96	1.03	1,570	1,954	2,089
250,000	0.86	0.97	1.03	962	1,101	1,169	0.95	1.04	1.11	2,030	2,213	2,353
300,000	0.92	....	....	1,139	.....	.....	1.00	....	....	2,270		
350,000	0.97	....	....	1,300	.....	.....	1.06	....	....	2,490		
400,000	1.02	....	....	1,473	.....	.....	1.10	....	....	2,720		
500,000	1.10	1.21	1.27	1,815	1,990	2,075	1.19	1.31	1.38	3,160	3,692	3,864
600,000	1.21	....	....	2,177	.....	.....	1.33	....	....	3,980		
700,000	1.28	....	....	2,512	.....	.....	1.40	....	....	4,420		
750,000	1.32	1.39	1.45	2,673	2,851	2,948	1.43	1.50	1.56	4,620	4,808	4,994
800,000	1.35	....	....	2,848	.....	.....	1.47	....	....	4,850		
900,000	1.41	....	....	3,194	.....	.....	1.53	....	....	5,265		
1,000,000	1.47	1.54	1.61	3,530	3,703	3,811	1.59	1.65	1.75	5,690	5,867	6,492
1,250,000	1.64	....	....	4,400	.....	.....	1.79	....	....	6,890		
1,500,000	1.76	1.84	1.90	5,240	5,441	5,570	1.91	1.97	2.04	7,875	8,497	8,727
1,750,000	1.88	....	....	6,060	.....	.....	2.02	....	....	8,890		
2,000,000	1.98	2.05	2.12	6,890	7,106	7,251	2.13	2.19	2.29	9,850	10,517	11,318

Braid-covered cables operating above 3,500 volts with neutral ungrounded must be shielded or suitably protected against corona.

The above data are approximate and subject to normal manufacturing tolerances.

145. Diameters and Weights of Solid and Concentric-stranded, Rubber-insulated, Twin-flat-construction, Two-conductor, Braided and Leaded Cables

(General Cable Corp.)

Size, A.w.g.	Braid covered						Lead sheathed					
	Over-all dimensions, in.			Weight, lb. per 1,000 ft.			Over-all dimensions, in.			Weight, lb. per 1,000 ft.		
	600 volts	2,001–3,000 volts	4,001–5,000 volts	600 volts	2,001–3,000 volts	4,001–5,000 volts	600 volts	2,001–3,000 volts	4,001–5,000 volts	600 volts	2,001–3,000 volts	4,001–5,000 volts
Solid												
14	0.41 × 0.22	.....	.....	62	.....	.....	0.44 × 0.25	.....	.....	218		
12	0.45 × 0.24	.....	.....	82	.....	.....	0.51 × 0.30	.....	.....	350		
10	0.49 × 0.26	0.45 × 0.84	0.59 × 1.07	114	227	371	0.55 × 0.32	0.51 × 0.86	0.60 × 1.05	403	979	1,258
8	0.60 × 0.32	0.54 × 0.92	0.62 × 1.12	174	308	435	0.66 × 0.38	0.53 × 0.91	0.63 × 1.10	532	1,080	1,367
6	0.68 × 0.36	0.55 × 0.95	0.65 × 1.14	285	418	496	0.77 × 0.45	0.60 × 1.04	0.66 × 1.17	800	1,328	1,522
4	.....	.....	.....	...	.....	.....	0.95 × 0.51	.....	.....	1,003		
Stranded												
14	0.43 × 0.23	.....	.....	64	.....	.....	0.46 × 0.26	.....	.....	228		
12	0.47 × 0.25	.....	.....	84	.....	.....	0.53 × 0.31	.....	.....	368		
10	0.52 × 0.27	.....	.....	124	.....	.....	0.57 × 0.33	.....	.....	425		
8	0.64 × 0.33	.....	.....	186	.....	.....	0.70 × 0.40	.....	.....	563		
6	0.72 × 0.38	0.57 × 1.04	0.66 × 1.18	295	446	527	0.81 × 0.47	0.62 × 1.08	0.71 × 1.24	848	1,397	1,843
4	.....	0.62 × 1.13	0.69 × 1.26	...	586	674	0.96 × 0.54	0.67 × 1.18	0.76 × 1.34	1,066	1,624	2,100
2	.....	0.68 × 1.25	0.75 × 1.38	...	794	890	1.03 × 0.58	0.76 × 1.33	0.82 × 1.46	1,310	2,213	2,450
1	.....	0.72 × 1.33	0.79 × 1.46	...	942	1,034	1.19 × 0.67	0.80 × 1.41	0.86 × 1.54	1,860	2,453	2,685
1/0	.....	0.76 × 1.42	0.83 × 1.54	...	1,104	1,213	1.27 × 0.72	0.84 × 1.49	0.90 × 1.62	2,120	2,705	2,955
2/0	.....	0.81 × 1.51	0.87 × 1.63	...	1,316	1,431	1.36 × 0.76	0.89 × 1.58	0.98 × 1.74	2,395	3,019	3,630
3/0	.....	0.86 × 1.61	0.92 × 1.74	...	1,583	1,706	1.47 × 0.81	0.94 × 1.69	1.03 × 1.85	2,730	3,403	4,041
4/0	.....	0.92 × 1.73	0.98 × 1.85	...	1,910	2,041	1.58 × 0.87	1.03 × 1.84	1.09 × 1.96	3,120	4,233	4,530

Braid-covered cables operating above 3.500 volts with neutral ungrounded must be shielded or suitably protected against corona.

The above data are approximate and subject to normal manufacturing tolerances.

146 Diameters and Weights of Solid and Concentric-stranded, Rubber-insulated, Braided and Leaded Cables

(General Cable Corp.)

Size, A.w.g. or cir. mils	Type	Two-conductor								Three-conductor							
		Braid covered				Lead sheathed				Braid covered				Lead sheathed			
		Over-all diam., in.		Weight, lb. per 1,000 ft.		Over-all diam., in.		Weight, lb. per 1,000 ft.		Over-all diam., in.		Weight, lb. per 1,000 ft.		Over-all diam., in.		Weight, lb. per 1,000 ft.	
		2,001–3,000 volts	4,001–5,000 volts	2,001–3,000 volts	4,001–5,000 volts	2,001–3,000 volts	4,001–5,000 volts	2,001–3,000 volts	4,001–5,000 volts	2,001–3,000 volts	4,001–5,000 volts	2,001–3,000 volts	4,001–5,000 volts	2,001–3,000 volts	4,001–5,000 volts	2,001–3,000 volts	4,001–5,000 volts
10	Solid	0.81	1.00	305	438	0.89	1.08	1,239	1,587	0.87	1.07	391	558	0.94	1.14	1,387	1,785
8	Solid	0.86	1.05	369	507	0.94	1.13	1,364	1,717	0.92	1.12	480	657	1.00	1.20	1,540	1,949
6	Solid	1.00	1.12	509	612	1.07	1.20	1,657	1,900	1.06	1.20	673	803	1.14	1.30	1,892	2,491
6	Stranded	1.05	1.16	548	653	1.12	1.27	1,744	2,296	1.11	1.24	722	856	1.18	1.35	1,996	2,608
4	Stranded	1.13	1.26	708	828	1.24	1.37	2,311	2,605	1.21	1.35	945	1,096	1.32	1.45	2,654	2,994
2	Stranded	1.25	1.38	951	1,080	1.36	1.49	2,721	3,024	1.34	1.48	1,280	1,446	1.45	1.58	3,170	3,522
1	Stranded	1.33	1.46	1,120	1,246	1.44	1.57	3,001	3,301	1.43	1.56	1,517	1,676	1.53	1.67	3,526	3,872
1/0	Stranded	1.42	1.54	1,306	1,447	1.52	1.65	3,301	3,615	1.51	1.65	1,779	1,963	1.62	1.79	3,909	4,713
2/0	Stranded	1.51	1.63	1,550	1,701	1.61	1.77	3,671	4,422	1.61	1.75	2,119	2,317	1.75	1.89	4,808	5,227
3/0	Stranded	1.61	1.74	1,847	2,014	1.75	1.87	4,534	4,906	1.72	1.86	2,543	2,756	1.86	2.00	5,414	5,848
4/0	Stranded	1.73	1.85	2,222	2,394	1.87	1.99	5,098	5,474	1.85	1.98	3,071	3,295	1.99	2.12	6,144	6,591
250,000	Stranded	1.88	2.01	2,622	2,811	2.02	2.15	5,755	6,148	2.01	2.15	3,627	3,870	2.15	2.32	6,975	8,003
350,000	Stranded	2.10	2.22	3,440	3,648	2.27	2.40	7,468	7,880	2.24	2.38	4,793	5,063	2.41	2.55	9,096	9,618
500,000	Stranded	2.36	2.49	4,648	4,885	2.54	2.67	9,330	9,790	2.53	2.66	6,510	6,816	2.70	2.83	11,355	11,913

Braid-covered cables operating above 3,500 volts with neutral ungrounded must be shielded or suitably protected against corona.
The above data are approximate and subject to normal manufacturing tolerances.

147. Diameters and Weights of Solid and Concentric-stranded, Varnished-cambric-insulated, Single-conductor, Braided and Leaded Cables

(General Cable Corp.)

Size, A.w.g. or cir. mils	Braided cables								Lead-sheathed cables							
	Over-all diam., in.				Weight, lb. per 1,000 ft.				Over-all diam., in.				Weight, lb. per 1,000 ft.			
	600 volts	2,001–3,000 volts	4,001–5,000 volts[a]	7,001–8,000 volts[a]	600 volts	2,001–3,000 volts	4,001–5,000 volts[a]	7,001–8,000 volts[a]	600 volts	2,001–3,000 volts	4,001–5,000 volts[a]	7,001–8,000 volts[a]	600 volts	2,001–3,000 volts	4,001–5,000 volts[a]	7,001–8,000 volts[a]
Solid																
14	0.253	.....	.....	.....	36	.....	.....	.....	0.252	.....	.....	.....	179			
12	0.300	.....	.....	.....	53	.....	.....	.....	0.269	.....	.....	.....	209			
10	0.321	0.355	.....	.....	69	78	.....	.....	0.290	0.384	.....	.....	230	322		
8	0.347	0.381	0.433	.....	91	101	123	.....	0.316	0.410	0.472	.....	269	362	426	
6	0.417	0.415	0.477	0.571	139	140	160	205	0.381	0.444	0.506	0.631	358	422	488	750
Stranded																
6	0.438	0.436	0.498	0.592	151	151	179	222	0.405	0.468	0.559	0.653	377	450	650	786
4	0.487	0.485	0.547	0.641	203	205	238	278	0.453	0.515	0.608	0.702	468	602	757	890
2	0.547	0.545	0.607	0.701	294	296	321	370	0.515	0.609	0.668	0.765	720	814	900	1,049
1	0.618	0.585	0.647	0.741	373	354	385	425	0.613	0.646	0.708	0.802	876	926	1,010	1,150
1/0	0.659	0.626	0.688	0.782	451	432	466	516	0.654	0.687	0.749	0.873	973	1,029	1,122	1,480

Diameters and Weights of Solid and Concentric-stranded, Varnished-cambric-insulated, Single-conductor, Braided and Leaded Cables (*Continued*)

Size, A.w.g. or cir. mils	Braided cables								Lead-sheathed cables							
	Over-all diam., in.				Weight, lb. per 1,000 ft.				Over-all diam., in.				Weight, lb. per 1,000 ft.			
	600 volts	2,001–3,000 volts	4,001–5,000 volts[a]	7,001–8,000 volts[a]	600 volts	2,001–3,000 volts	4,001–5,000 volts[a]	7,001–8,000 volts[a]	600 volts	2,001–3,000 volts	4,001–5,000 volts[a]	7,001–8,000 volts[a]	600 volts	2,001–3,000 volts	4,001–5,000 volts[a]	7,001–8,000 volts[a]
2/0	0.705	0.672	0.734	0.828	548	528	557	615	0.700	0.733	0.795	0.919	1,116	1,168	1,267	1,640
3/0	0.756	0.723	0.785	0.899	661	635	672	754	0.751	0.784	0.876	0.970	1,290	1,338	1,640	1,818
4/0	0.814	0.781	0.843	0.957	810	781	822	908	0.809	0.872	0.934	1.028	1,690	1,750	1,858	2,038
250,000	0.913	0.858	0.941	1.004	966	942	991	1,043	0.919	0.950	1.012	1.075	1,926	1,987	2,104	2,231
300,000	0.988	.....	.....	.....	1,153	.....	.....	.....	0.974	.....	.....	.....	2,170			
350,000	1.040	.....	.....	.....	1,327	.....	.....	.....	1.026	.....	.....	.....	2,386			
400,000	1.086	.....	.....	.....	1,490	.....	.....	.....	1.072	.....	.....	.....	2,609			
450,000	1.135	.....	.....	.....	1,672	.....	.....	.....	1.121	.....	.....	.....	2,825			
500,000	1.172	1.147[b]	1.210[b]	1.273[b]	1,866	1,803[b]	1,866[b]	1,940[b]	1.158	1.190	1.283	1.346	3,040	3,247	3,545	3,700
550,000	1.213	.....	.....	.....	2,023	.....	.....	.....	1.261	.....	.....	.....	3,548			
600,000	1.282	.....	.....	.....	2,238	.....	.....	.....	1.300	.....	.....	.....	3,850			
700,000	1.366	.....	.....	.....	2,591	.....	.....	.....	1.384	.....	.....	.....	4,298			
750,000	1.388	1.333[b]	1.395[b]	1.458[b]	2,762	2,655[b]	2,711[b]	2,798[b]	1.406	1.406	1.468	1.531	4,400	4,400	4,661	4,820
1,000,000	1.541	1.486[b]	1.548[b]	1.611[b]	3,577	3,458[b]	3,535[b]	3,621[b]	1.559	1.559	1.621	1.684	5,518	5,518	5,689	5,852
1,500,000	1.861	1.806[b]	1.837[b]	1.900[b]	5,310	5,165[b]	5,213[b]	5,307[b]	1.894	1.894	1.925	1.988	8,101	8,101	8,201	8,399
1,750,000	1.973	.....	.....	.....	6,107	.....	.....	.....	2.006	.....	.....	.....	9,076			
2,000,000	2.067	2.012[b]	2.043[b]	2.106[b]	6,975	6,814[b]	6,870[b]	6,974[b]	2.110	2.110	2.131	2.194	10,091	10,091	10,197	10,406

The above data are approximate and subject to normal manufacturing tolerances.

[a] For ungrounded-neutral service, heavier insulation walls are required. See Tables 118, 119, and 122.

[b] Weights and diameters are for cables with tape and braid; other braided cables have single braid only.

148. Data for Solid and Concentric-stranded, Varnished-cambric-insulated, Two- and Three-conductor, Braided and Leaded, 2,000- to 8,000-Volt Cable

(General Cable Corp.)

Rated voltage, phase to phase	Conductor		Varnished-cambric thickness		Two-conductor cables					Three-conductor cables				
					Braid covered		Lead sheathed			Braid covered		Lead sheathed		
	Size, A.w.g. or cir. mils	Type	Conductor, in.	Belt, in.	Over-all diam., in.	Weight, lb. per 1,000 ft.	Sheath thickness, in.	Over-all diam., in.	Weight, lb. per 1,000 ft.	Over-all diam., in.	Weight, lb. per 1,000 ft.	Sheath thickness, in.	Over-all diam., in.	Weight, lb. per 1,000 ft.
2,001–3,000 (grounded or ungrounded)	10	Solid	5/64	2/64	0.644	215	4/64	0.704	786	0.683	269	4/64	0.743	925
	8	Solid	5/64	2/64	0.696	275	4/64	0.756	900	0.739	344	4/64	0.800	1,058
	6	Solid	5/64	2/64	0.764	373	4/64	0.825	1,054	0.812	466	5/64	0.903	1,466
	6	Stranded	5/64	2/64	0.806	389	5/64	0.897	1,311	0.857	486	5/64	0.948	1,542
	4	Stranded	5/64	2/64	0.924	565	5/64	0.995	1,585	0.982	706	5/64	1.053	1,865
	2	Stranded	5/64	2/64	1.044	822	5/64	1,115	1,966	1.141[a]	1,027[a]	5/64	1,182	2,313
	1	Stranded	6/64	2/64	1.218[a]	1,058[a]	6/64	1.291	2,645	1.296[a]	1,322[a]	6/64	1.369	3,112
	1/0	Stranded	6/64	2/64	1.300[a]	1,262[a]	6/64	1.373	2,970	1.384[a]	1,578[a]	6/64	1.457	3,494
	2/0	Stranded	6/64	2/64	1.392[a]	1,526[a]	6/64	1.465	3,369	1.483[a]	1,908[a]	6/64	1.556	3,963
	3/0	Stranded	6/64	2/64	1.494[a]	1,849[a]	6/64	1.567	3,840	1.593[a]	2,311[a]	6/64	1.666	4,518
	4/0	Stranded	6/64	2/64	1.610[a]	2,256[a]	6/64	1.683	4,413	1.717[a]	2,820[a]	7/64	1.820	5,647
	250,000	Stranded	6/64	2/64	1.704[a]	2,598[a]	7/64	1.807	5,311	1.818[a]	3,248[a]	7/64	1.922	6,248
	500,000	Stranded	6/64	2/64	2.197[a]	4,852[a]	8/64	2.332	8,959	2.347[a]	6,065[a]	8/64	2.482	10,540
	750,000	Stranded	6/64	3/64	2.598[a]	7,106[a]	8/64	2.733	12,058	2.776[a]	8,883[a]	8/64	2.911	14,186
	1,000,000	Stranded	7/64	3/64	2.904[a]	9,244[a]	8/64	3.039	14,860	3.105[a]	11,555[a]	8/64	3.240	17,483
4,001–5,000 (grounded or ungrounded)	8	Solid	6/64	4/64	0.822	354	5/64	0.913	1,275	0.889	442	5/64	0.960	1,500
	6	Solid	6/64	4/64	0.910	460	5/64	0.981	1,452	0.962	575	5/64	1.034	1,708
	6	Stranded	6/64	4/64	0.952	482	5/64	1.023	1,530	1.008	603	5/64	1.080	1,801
	4	Stranded	6/64	4/64	1.050	661	5/64	1.121	1,808	1.143[a]	826[a]	5/64	1.185	2,127
	2	Stranded	7/64	3/64	1.200[a]	937[a]	6/64	1.273	2,482	1.272[a]	1,171[a]	6/64	1.346	2,920

Data for Solid and Concentric-stranded, Varnished-cambric-insulated, Two- and Three-conductor, Braided and Leaded, 2,000- to 8,000-Volt Cable (*Continued*)

Rated voltage, phase to phase	Conductor		Varnished-cambric thickness		Two-conductor cables					Three-conductor cables				
					Braid covered		Lead sheathed			Braid covered		Lead sheathed		
	Size, A.w.g. or cir. mils	Type	Conductor, in.	Belt, in.	Over-all diam., in.	Weight, lb. per 1,000 ft.	Sheath thickness, in.	Over-all diam., in.	Weight, lb. per 1,000 ft.	Over-all diam., in.	Weight, lb. per 1,000 ft.	Sheath thickness, in.	Over-all diam., in.	Weight, lb. per 1,000 ft.
	1	Stranded	6/64	4/64	1.280[a]	1,108[a]	5/64	1.353	2,778	1.358[a]	1,385[a]	6/64	1.432	3,268
	1/0	Stranded	6/64	4/64	1.362[a]	1,318[a]	5/64	1.435	3,111	1.446[a]	1,648[a]	6/64	1.520	3,660
	2/0	Stranded	6/64	4/64	1.454[a]	1,586[a]	6/64	1.527	3,506	1.545[a]	1,983[a]	6/64	1.619	4,125
	3/0	Stranded	6/64	4/64	1.556[a]	1,914[a]	6/64	1.629	3,982	1.655[a]	2,393[a]	7/64	1.759	5,125
	4/0	Stranded	6/64	4/64	1.672[a]	2,320[a]	7/64	1.775	4,964	1.779[a]	2,900[a]	7/64	1.883	5,840
	250,000	Stranded	7/64	4/64	1.828[a]	2,744[a]	7/64	1.931	5,655	1.947[a]	3,430[a]	7/64	2.049	6,653
	500,000	Stranded	7/64	4/64	2.321[a]	5,024[a]	8/64	2.456	9,381	2.476[a]	6,280[a]	8/64	2.611	11,037
	750,000	Stranded	7/64	4/64	2.691[a]	7,275[a]	8/64	2.826	12,397	2.874[a]	9,094[a]	8/64	3.009	14,585
	1,000,000	Stranded	7/64	4/64	2.997[a]	9,446[a]	8/64	3.132	15,220	3.203[a]	11,808[a]	9/64	3.369	18,747
7,001–8,000 (grounded)[b]	6	Solid	7/64	6/64	1.035	562	5/64	1.106	1,675	1.122[a]	703[a]	5/64	1.163	1,970
	6	Stranded	7/64	6/64	1.077	596	5/64	1.148	1,749	1.167[a]	745[a]	5/64	1.206	2,058
	4	Stranded	7/64	6/64	1.205[a]	781[a]	6/64	1.246	2,310	1.273[a]	976[a]	6/64	1.344	2,718
	2	Stranded	7/64	6/64	1.325[a]	1,038[a]	6/64	1.398	2,754	1.402[a]	1,298[a]	6/64	1.473	3,240
	1	Stranded	7/64	6/64	1.405[a]	1,222[a]	6/64	1.478	3,053	1.488[a]	1,527[a]	6/64	1.559	3,592
	1/0	Stranded	7/64	6/64	1.487[a]	1,450[a]	6/64	1.560	3,390	1.576[a]	1,813[a]	6/64	1.647	3,988
	2/0	Stranded	7/64	6/64	1.579[a]	1,725[a]	6/64	1.652	3,805	1.675[a]	2,156[a]	7/64	1.776	4,921
	3/0	Stranded	7/64	6/64	1.681[a]	2,050[a]	7/64	1.784	4,688	1.784[a]	2,562[a]	7/64	1.885	5,515
	4/0	Stranded	7/64	6/64	1.797[a]	2,466[a]	7/64	1.900	5,304	1.909[a]	3,083[a]	7/64	2.010	6,240
	250,000	Stranded	7/64	6/64	1.891[a]	2,822[a]	7/64	1.994	5,824	2.010[a]	3,528[a]	7/64	2.111	6,852
	500,000	Stranded	7/64	6/64	2.384[a]	5,132[a]	8/64	2.519	9,580	2.539[a]	6,415[a]	8/64	2.674	11,271
	750,000	Stranded	7/64	6/64	2.754[a]	7,392[a]	8/64	2.889	12,629	2.937[a]	9,240[a]	8/64	3.072	14,858
	1,000,000	Stranded	7/64	6/64	3.060[a]	9,577[a]	8/64	3.195	15,457	3.266[a]	11,971[a]	9/64	3.432	19,043

The above data are approximate and subject to normal manufacturing tolerances.

[a] Weights and diameters are for cables with tape and braid; other braided cables have single braid only.

[b] For ungrounded-neutral service, heavier insulation walls are required, see Tables 116 to 119.

All conductors untinned, soft annealed copper (also supplied with tin or alternate special Amaloy-coated strands).

149. Diameters and Weights of Solid and Concentric-stranded, Varnished-cambric-insulated, Three-conductor, 600-volt, Braided and Leaded Cables

(General Cable Corp.)

Size, A.w.g. or cir. mils	Taped and braided cables		Lead-sheathed cables		
	Over-all diam., in.	Weight, lb. per 1,000 ft.	Sheath thickness, in.	Over-all diam., in.	Weight, lb. per 1,000 ft.
Solid					
14	0.420	103	3/64	0.449	390
12	0.456	131	3/64	0.485	445
10	0.501	187	4/64	0.562	663
8	0.557	257	4/64	0.618	788
6	0.697	395	4/64	0.757	1,066
Stranded					
6	0.742	412	4/64	0.803	1,128
4	0.848	598	5/64	0.939	1,641
2	0.997	899	5/64	1.068	2,076
1	1.164	1,172	6/64	1.252	2,825
1/0	1.252	1,441	6/64	1.340	3,202
2/0	1.351	1,756	6/64	1.439	3,661
3/0	1.461	2,146	6/64	1.549	4,204
4/0	1.586	2,630	6/64	1.674	4,868
250,000	1.755	3,149	7/64	1.873	6,087
300,000	1.874	3,708	7/64	1.992	6,847
350,000	1.986	4,258	7/64	2.104	7,584
400,000	2.084	4,796	7/64	2.202	8,289
450,000	2.205	5,356	8/64	2.340	9,566
500,000	2.284	5,916	8/64	2.419	10,292
550,000[a]	2.436	6,617	8/64	2.571	11,260
600,000[a]	2.517	7,169	8/64	2.652	11,979
700,000[a]	2.698	8,289	8/64	2.833	13,444
750,000[a]	2.745	8,817	8/64	2.880	14,061
1,000,000[a]	3.074	11,478	8/64	3.209	17,349

The above data are approximate and subject to normal manufacturing tolerances.

[a] These cables are belted; all others are nonbelted.

150. Diameters and Weights of Compack-stranded, Round, Solid-type, Paper-insulated, Single-conductor Leaded Cables

(General Cable Corp.)

Size, A.w.g. or cir. mils	0–1,000 volts, grounded or ungrounded	2,001–3,000 volts, grounded or ungrounded	4,001–5,000 volts, grounded or ungrounded	7,001–8,000 volts, grounded	7,001–8,000 volts, ungrounded	14,001–15,000 volts, grounded	14,001–15,000 volts, ungrounded	22,001–23,000 volts, grounded	22,001–23,000 volts, ungrounded	34,001–35,000 volts, grounded	34,001–35,000 volts, ungrounded	45,001–46,000 volts, grounded	68,001–69,000 volts, grounded
	Over-all diameters, in., for cables of designated phase-to-phase voltage ratings												
1	0.610	0.641	0.673	0.781	0.813	0.906	1.000	1.031	1.205				
1/0	0.647	0.678	0.710	0.818	0.850	0.943	1.037	1.068	1.242	1.304	1.538		
2/0	0.688	0.719	0.741	0.859	0.891	0.984	1.095	1.126	1.283	1.345	1.579		
3/0	0.734	0.780	0.812	0.905	0.937	1.030	1.141	1.172	1.329	1.406	1.625	1.594	
4/0	0.802	0.832	0.864	0.957	0.989	1.099	1.193	1.224	1.381	1.458	1.677	1.645	
250,000	0.847	0.877	0.909	1.002	1.034	1.143	1.238	1.269	1.441	1.503	1.738	1.691	
300,000	0.897	0.927	0.959	1.052	1.101	1.194	1.288	1.319	1.491	1.553	1.789	1.758	
350,000	0.943	0.973	1.005	1.115	1.147	1.240	1.334	1.365	1.537	1.599	1.834	1.803	2.257
400,000	0.986	1.016	1.048	1.158	1.190	1.283	1.377	1.423	1.580	1.642	1.877	1.846	2.318
500,000	1.064	1.111	1.143	1.236	1.268	1.361	1.470	1.501	1.658	1.736	1.954	1.923	2.394
600,000	1.187	1.219	1.219	1.312	1.344	1.452	1.546	1.577	1.750	1.812	2.046	2.000	2.499
750,000	1.282	1.314	1.314	1.422	1.454	1.547	1.641	1.672	1.845	1.907	2.141	2.110	2.583
1,000,000	1.436	1.469	1.469	1.562	1.594	1.687	1.797	1.828	1.985	2.062	2.281	2.250	2.719
	Weight, lb. per 1,000 ft. for cables of designated phase-to-phase voltage ratings												
1	910	960	1,016	1,279	1,342	1,508	1,703	1,768	2,276				
1/0	1,029	1,082	1,137	1,409	1,473	1,638	1,841	1,907	2,426	2,580	3,339		
2/0	1,168	1,222	1,279	1,543	1,608	1,801	2,143	2,217	2,603	2,763	3,536		
3/0	1,337	1,496	1,558	1,726	1,791	1,989	2,346	2,421	2,814	3,156	3,768	3,676	
4/0	1,648	1,712	1,755	1,945	2,013	2,358	2,586	2,662	3,069	3,395	4,039	3,946	
250,000	1,806	1,873	1,934	2,131	2,202	2,558	2,791	2,866	3,441	3,610	4,493	4,174	
300,000	2,033	2,098	2,166	2,368	2,582	2,807	3,043	3,123	3,712	3,890	4,791	4,688	
350,000	2,256	2,321	2,390	2,741	2,817	3,047	3,288	3,374	3,975	4,158	5.066	4.963	6,845
400,000	2,468	2,536	2,503	2,968	3,043	3,281	3,527	3,772	4,225	4,410	5,338	5,234	7,227
500,000	2,875	3,104	3,178	3,410	3,490	3,734	4,153	4,245	4,712	5,125	5,858	5,749	7,964
600,000	3,524	3,599	3,599	3,838	3,922	4,340	4,611	4,703	5,407	5,610	6,624	6,254	8,669
750,000	4,131	4,203	4,203	4,625	4,715	4,986	5,267	5,361	6,098	6,306	7,360	7,242	9,486
1,000,000	5,279	5,368	5,368	5,642	5,740	6,022	6,552	6,656	7,199	7,684	8,524	8,402	11,137

The above data are approximate and subject to normal manufacturing tolerances.

151. Diameters of Solid and Concentric-stranded, Solid-type, Paper-insulated, Single-conductor Leaded Cables

(General Cable Corp.)

Size, A.w.g. or cir. mils	Over-all diameters, in., for cables of designated phase-to-phase voltage ratings												
	0–1,000 volts, grounded or ungrounded	2,001–3,000 volts, grounded or ungrounded	4,001–5,000 volts, grounded or ungrounded	7,001–8,000 volts, grounded	7,001–8,000 volts, ungrounded	14,001–15,000 volts, grounded	14,001–15,000 volts, ungrounded	22,001–23,000 volts, grounded	22,001–23,000 volts, ungrounded	34,001–35,000 volts, grounded	34,001–35,000 volts, ungrounded	45,001–46,000 volts, grounded	68,001–69,000 volts, grounded
8	0.435	0.464	0.494										
6	0.471	0.500	0.531	0.651	0.683	0.791	0.885						
4	0.543	0.574	0.606	0.699	0.731	0.839	0.933						
2	0.603	0.634	0.666	0.774	0.806	0.899	0.993	1.024	1.198				
1	0.644	0.675	0.707	0.816	0.848	0.941	1.035	1.066	1.238				
1/0	0.685	0.761	0.748	0.857	0.889	0.982	1.091	1.122	1.279	1.341	1.576		
2/0	0.731	0.778	0.810	0.903	0.935	1.028	1.137	1.168	1.325	1.387	1.622		
3/0	0.798	0.829	0.861	0.969	1.001	1.094	1.188	1.219	1.376	1.454	1.673	1.642	
4/0	0.856	0.887	0.919	1.012	1.044	1.152	1.246	1.277	1.450	1.512	1.746	1.699	
250,000	0.903	0.934	0.966	1.059	1.106	1.198	1.293	1.324	1.497	1.559	1.793	1.762	
300,000	0.958	0.989	1.021	1.129	1.161	1.254	1.348	1.379	1.552	1.614	1.849	1.818	
350,000	1.009	1.040	1.072	1.180	1.212	1.305	1.415	1.446	1.603	1.665	1.899	1.868	2.321
400,000	1.056	1.102	1.134	1.227	1.259	1.352	1.462	1.493	1.650	1.727	1.946	1.915	2.383
500,000	1.157	1.188	1.220	1.313	1.345	1.454	1.548	1.579	1.751	1.813	2.047	2.000	2.468
600,000	1.267	1.299	1.299	1.408	1.440	1.533	1.627	1.658	1.830	1.892	2.127	2.096	2.549
750,000	1.372	1.420	1.420	1.513	1.545	1.638	1.747	1.778	1.935	1.997	2.232	2.201	2.669
1,000,000	1.542	1.574	1.574	1.667	1.699	1.807	1.901	1.932	2.105	2.167	2.401	2.370	2.823
1,250,000	1.726	1.757	1.757	1.819	1.851	1.944	2.053	2.084	2.241	2.303	2.538	2.507	2.960
1,500,000	1.849	1.880	1.880	1.942	1.974	2.082	2.176	2.207	2.380	2.442	2.676	2.630	3.100
1,750,000	1.962	1.993	1.993	2.070	2.094	2.195	2.289	2.320	2.493	2.555	2.789	2.758	3.213
2,000,000	2.084	2.115	2.115	2.177	2.209	2.302	2.412	2.443	2.600	2.677	2.896	2.865	3.321

The above data are approximate and subject to normal manufacturing tolerances.
Sizes Nos. 8 and 6 are solid round. All other sizes are concentric, round stranded.

152. Weights of Solid and Concentric-stranded, Solid-type, Paper-insulated, Single-conductor Leaded Cables
(General Cable Corp.)

Size, A.w.g. or cir. mils	Weight, lb., per 1,000 ft., for cables of designated phase-to-phase voltage ratings												
	0–1,000 volts, grounded or ungrounded	2,001–3,000 volts, grounded or ungrounded	4,001–5,000 volts, grounded or ungrounded	7,001–8,000 volts, grounded	7,001–8,000 volts, ungrounded	14,001–15,000 volts, grounded	14,001–15,000 volts, ungrounded	22,001–23,000 volts, grounded	22,001–23,000 volts, ungrounded	34,001–35,000 volts, grounded	34,001–35,000 volts, ungrounded	45,001–46,000 volts, grounded	68,001–69,000 volts, grounded
8	478	517	564										
6	550	594	644	833	890	1,155	1,347						
4	690	741	793	954	1,011	1,288	1,471						
2	848	901	955	1,217	1,281	1,471	1,659	1,728	2,239				
1	955	1,009	1,066	1,337	1,402	1,586	1,790	1,859	2,383				
1/0	1,080	1,135	1,192	1,472	1,539	1,722	2,069	2,143	2,540	2,701	3,502		
2/0	1,226	1,378	1,442	1,622	1,690	1,892	2,244	2,321	2,725	2,892	3,709		
3/0	1,501	1,462	1,629	1,813	1,881	2,224	2,456	2,535	2,946	3,295	3,750	3,855	
4/0	1,721	1,679	1,843	2,042	2,114	2,468	2,707	2,786	3,387	3,560	4,443	4,137	
250,000	1,898	1,965	2,032	2,237	2,449	2,677	2,921	2,999	3,608	3,784	4,699	4,590	
300,000	2,135	2,202	2,273	2,623	2,701	2,937	3,184	3,267	3,891	4,077	5,009	4,902	
350,000	2,366	2,434	2,506	2,867	2,947	3,188	3,613	3,529	4,165	4,357	5,296	5,189	7,095
400,000	2,588	2,794	2,871	3,104	3,187	3,432	3,868	3,952	4,426	4,832	5,580	5,472	7,683
500,000	3,164	3,243	3,323	3,566	3,650	4,082	4,350	4,446	5,149	5,357	6,372	6,009	8,284
600,000	3,679	3,764	3,764	4,185	4,277	4,545	4,828	4,924	5,651	5,863	6,911	6,792	8,981
750,000	4,315	4,575	4,575	4,841	4,935	5,219	5,728	5,830	6,372	6,590	7,678	7,555	10,000
1,000,000	5,521	5,618	5,618	5,902	6,005	6,521	6,845	6,953	7,520	8,015	9,182	9,051	11,315
1,250,000	6,836	6,949	6,949	7,156	7,266	7,591	8,175	8,294	8,903	9,150	10,348	10,230	12,592
1,500,000	7,851	7,959	7,959	8,175	8,289	8,879	9,239	9,360	10,278	10,542	11,821	11,349	14,437
1,750,000	8,838	8,950	8,950	9,427	9,516	9,907	10,280	10,405	11,355	11,608	12,949	12,799	15,667
2,000,000	10,070	10,187	10,187	10,427	10,552	10,923	11,598	11,730	12,398	13,009	14,051	13,900	17,657

The above data are approximate and subject to normal manufacturing tolerances.
Size Nos. 8 and 6 are solid round. All other sizes are concentric, round stranded.

153. Diameters and Weights of Annular, Concentric-stranded, Rope-core, and Compack Segmental-stranded, Solid-type, Paper-insulated, Single-conductor Leaded Cables

(General Cable Corp.)

Size, cir. mils	Annular, concentric stranded, rope core								Compack, segmental stranded							
	14,001–15,000 volts, grounded		14,001–15,000 volts, ungrounded		22,001–23,000 volts, grounded		22,001–23,000 volts, ungrounded		14,001–15,000 volts, grounded		14,001–15,000 volts, ungrounded		22,001–23,000 volts, grounded		22,001–23,000 volts, ungrounded	
	Over-all diam., in.	Weight, lb. per 1,000 ft.	Over-all diam., in.	Weight, lb. per 1,000 ft.	Over-all diam., in.	Weight, lb. per 1,000 ft.	Over-all diam., in.	Weight, lb. per 1,000 ft.	Over-all diam., in.	Weight, lb. per 1,000 ft.	Over-all diam., in.	Weight, lb. per 1,000 ft.	Over-all diam., in.	Weight, lb. per 1,000 ft.	Over-all diam., in.	Weight, lb. per 1,000 ft.
1,000,000	2.019	7,825	2.130	8,494	2.162	8,629	2.318	9,334	1.807	6,521	1.901	6,845	1.932	6,953	2.104	7,777
1,250,000	2.223	9,394	2.317	9,810	2.365	10,257	2.521	11,011	1.944	7,591	2.053	8,175	2.084	8,294	2.241	8,903
1,500,000	2.489	10,958	2.583	11,404	2.615	11,554	2.787	12,679	2.082	8,879	2.176	9,239	2.207	9,360	2.380	10,278
1,750,000	2.629	12,208	2.739	13,005	2.771	13,165	2.927	13,988	2.195	9,907	2.289	10,280	2.320	10,405	2.493	11,355
2,000,000	2.846	13,779	2.940	14,268	2.972	14,431	3.144	15,655	2.302	10,923	2.412	11,598	2.443	11,730	2.600	12,398
2,500,000	3.142	16,580	3.236	17,802	3.268	17,275	3.455	19,023	2.510	13,708	2.605	14,121	2.635	14,262	2.808	15,335
3,000,000	3.406	20,799	3.500	20,362	3.532	21,519	3.703	22,940	2.730	16,175	2.824	16,619	2.855	16,770	3.027	17,883
3,500,000	3.801	25,215	3.895	25,802	3.927	26,001	4.099	27,519	2.891	17,977	3.000	18,736	3.031	18,893	3.188	19,786
4,000,000	4.100	28,618	4.208	29,240	4.238	29,452	4.394	30,516	3.056	20,308	3.150	20,793	3.181	20,960	3.369	22,344

The above data are approximate and subject to normal manufacturing tolerances.

154. Diameters and Weights of Three-conductor, Solid-type, Paper-insulated, Belted and Leaded Cables

(General Cable Corp.)

Size, A.w.g. or cir. mils	Diameters and weights for designated phase-to-phase voltage ratings													
	0–1,000 volts, grounded or ungrounded		2,001–3,000 volts, grounded or ungrounded		4,001–5,000 volts, grounded or ungrounded		7,001–8,000 volts, grounded		7,001–8,000 volts, ungrounded		14,000–15,000 volts, grounded		14,001–15,000 volts, ungrounded	
	Over-all diam., in.	Weight, lb. per 1,000 ft.	Over-all diam., in.	Weight, lb. per 1,000 ft.	Over-all diam., in.	Weight, lb. per 1,000 ft.	Over-all diam., in.	Weight, lb. per 1,000 ft.	Over-all diam., in.	Weight, lb. per 1,000 ft.	Over-all diam., in.	Weight, lb. per 1,000 ft.	Over-all diam., in.	Weight, lb. per 1,000 ft.
8	0.826	1,252	0.919	1,430	1.014	1,632								
6	0.904	1,470	0.997	1,665	1.109	2,012	1.172	2,163	1.261	2,387	1.483	3,055	1.640	3,514
4	1.055	1,884	1.170	2,240	1.270	2,486	1.337	2,655	1.446	3,075	1.586	3,468	1.759	4,152
2	1.202	2,508	1.300	2,748	1.415	3,175	1.482	3,363	1.576	3,623	1.732	4,249	1.889	4,760
1	1.217	2,719	1.315	3,058	1.430	3,400	1.497	3,557	1.591	3,818	1.747	4,449	1.904	4,942
1/0	1.192	2,878	1.284	3,104	1.377	3,339	1.452	3,666	1.546	3,928	1.667	4,284	1.840	4,997
2/0	1.272	3,299	1.363	3,533	1.471	3,947	1.532	4,121	1.626	4,394	1.762	4,979	1.919	5,491
3/0	1.360	3,808	1.467	4,225	1.560	4,487	1.621	4,664	1.731	5,170	1.851	5,556	2.008	6,084
4/0	1.475	4,605	1.567	4,869	1.660	5,143	1.737	5,551	1.831	5,854	1.951	6,256	2.123	7,069
250,000	1.623	5,320	1.654	5,415	1.764	5,928	1.824	6,122	1.918	6,435	2.054	7,112	2.211	7,691
300,000	1.736	6,239	1.767	6,340	1.860	6,645	1.921	6,852	2.015	7,173	2.150	7,873	2.307	8,432
350,000	1.824	6,926	1.855	7,031	1.949	7,347	2.009	7,553	2.118	8,147	2.238	8,607	2.411	9,524
400,000	1.908	7,597	1.939	7,701	2.047	8,290	2.108	8,512	2.202	8,863	2.322	9,326	2.495	10,241
500,000	2.073	9,181	2.104	9,295	2.197	9,646	2.257	9,873	2.367	10,543	2.488	11,017	2.645	11,684
600,000	2.221	10,485	2.252	10,604	2.361	11,270	2.421	11,490	2.515	11,881	2.636	12,399	2.808	13,454
700,000	2.362	12,063	2.393	12,165	2.487	12,552	2.547	12,808	2.641	13,213	2.776	14,101	2.933	14,832
750,000	2.419	12,669	2.450	12,798	2.544	13,194	2.604	13,450	2.713	14,213	2.833	14,763	3.006	15,891

The above data are approximate and subject to normal manufacturing tolerances.
Sizes Nos. 8 and 6 are solid round. Sizes Nos. 4 and 2 are concentric, round stranded. Size No. 1 is compack, round stranded. Sizes 1/0 to 750,000 cir. mils are compack, sector stranded.

155. Diameters and Weights of Three-conductor, Paper-insulated, Shielded and Leaded Cables (General Cable Corp.)

Size, A.w.g. or cir. mils	Diameters and weights for designated phase-to-phase voltage ratings										Diameters and weights for designated phase-to-phase voltage ratings							
	14,001–15,000 volts, grounded		14,001–15,000 volts, ungrounded		22,001–23,000 volts, grounded		22'001–23,000 volts, ungrounded		34,001–35,000 volts, grounded		23,000 volts, grounded		34,500 volts, grounded		46,000 volts, grounded		69,000 volts, grounded	
	Over-all diam., in.	Wt., lb. per 1,000 ft.	Over-all diam., in.	Wt., lb. per 1,000 ft.	Over-all diam., in.	Wt., lb. per 1,000 ft.	Over-all diam., in.	Wt., lb. per 1,000 ft.	Over-all diam., in.	Wt., lb. per 1,000 ft.	Over-all diam., in.	Wt. lb. per 1,000 ft.	Over-all diam., in.	Wt., lb. per 1,000 ft.	Over-all diam., in.	Wt., lb. per 1,000 ft.	Over-all diam., in.	Wt., lb. per 1,000 ft.
	Type H, concentric round-stranded										Oil-filled							
6	1.563	3,405	1.760	4,203														
4	1.663	3,961	1.890	4,765														
2	1.820	4,670	2.045	5,570	2.114	5,813	2.480	7,590										
	Type H, compack round										Compack round							
1	1.850	4,930	2.064	5,834	2.134	6,095	2.500	7,840										
1/0					2.226	6,556	2.580	8,220	2.729	9,158	1.52	4.155						
2/0									2.815	9,776								
3/0									2.917	10,510								
	Type H, solid-type compack, sector-stranded																	
1/0	1.790	5,035	1.990	5,690														
2/0	1.880	5,540	2.104	6,461	2.174	6,712	2.530	8,330			1.59	4,592	1.80	5,585	1.96	6,361	2 49	8,244
3/0	1.970	6,125	2.194	7,102	2.264	7,353	2.630	9,005			1.67	5,329	1.89	6,149	2.06	6,942	2.48	8,829
4/0	2.074	7,077	2.284	7,826	2.370	8,400	2.735	10,155	2.865	10,752	1.80	5,957	1.98	6,864	2.16	7,662	2.57	9,659
250.000	2.154	7,648	2.370	8,770	2.440	9,050	2.805	10,878	2.945	11,495	1.88	6,730	2.08	7,682	2.23	8,280	2.65	10,330
300,000	2.244	8,404	2.470	9,515	2.530	9,800	2.895	11,623	3.050	12,610	1.96	8,087	2.16	9,094	2.32	9,686	2.75	11,544
350,000	2.314	9,109	2.540	10,300	2.610	10,600	2.991	12,845	3.120	13,470	2.07	8,385	2.25	9,183	2.42	10,101	2 84	12,232
											Compack, sector stranded						Compack round	
400,000	2.420	10,150	2.630	11,050	2.705	11,707	3.070	13,640	3.210	14,270	2.14	9,082	2.32	9,902	2.49	10,824	2.91	13,037
500,000	2.570	11,600	2.795	12,892	2.855	13,221	3.220	15,210	3.392	16,728	2.28	10,410	2.48	11,548	2.63	12,223	3.07	14,880
600,000	2.705	13,318	2.914	14,244	3.000	14,970	3.382	17,556	3.520	17,190	2.41	12,744	2.59	12,901	2.76	13,932	3.18	16,319
700,000	2.835	14,767	3.060	16,080	3.130	16,430	3.500	19,000	3.655	20,229	2.57	13,742	2.75	14,989	2.88	15,364	3.29	17,862
750,000	2.884	15,361	3.110	16,750	3.180	17,100	3.560	19,730	3.715	20,978	2.62	14,382	2.80	15,663	2.92	16,037	3.37	18,982

156. Diameters and Weights of Oil-filled, Paper-insulated, Single-conductor, Concentric-stranded, Hollow-core Cable

(General Cable Corp.)

Rated voltage, phase to phase	Size, A.w.g. or cir. mils	Over-all diam., in.		Weight, lb. per 1,000 ft.	
		Core i.d. = 0.50 in.	Core i.d. = 0.69 in.	Core i.d. = 0.50 in.	Core i.d. = 0.69 in.
69,000 (grounded)	2/0	1.59	....	4,201	
	3/0	1.62	1.79	4,388	5,076
	4/0	1.66	1.82	4,612	5,290
	250,000	1.69	1.85	4,801	5,471
	300,000	1.75	1.89	5,272	5,721
	350,000	1.78	1.91	5,508	5,958
	400,000	1.82	1.95	5,761	6,271
	450,000	1.86	1.98	5,998	6,670
	500,000	1.90	2.01	6,234	7,047
	600,000	1.95	2.09	6,663	7,364
	650,000	1.99	2.11	6,918	7,589
	700,000	2.02	2.14	7,155	7,807
	750,000	2.06	2.17	7,642	8,039
	800,000	2.10	2.19	7,868	8,245
	850,000	2.13	2.23	8,104	8,481
	900,000	2.15	2.25	8,346	8,700
	1,000,000	2.19	2.30	8,778	9,134
	1,250,000	2.32	2.43	9,872	10,527
	1,500,000	2.45	2.54	11,060	11,319
	1,750,000	2.55	2.63	12,121	12,381
	2,000,000	2.66	2.75	13,141	13,747
115,000 (grounded)	4/0	2.00	2.17	6,342	6,557
	250,000	2.03	2.20	6,643	6,740
	300,000	2.09	2.23	6,794	7,019
	350,000	2.13	2.26	7,113	7,329
	400,000	2.17	2.30	7,333	7,506
	450,000	2.20	2.33	7,423	7,716
	500,000	2.24	2.37	7,667	8,244
	600,000	2.30	2.44	8,133	8,729
	650,000	2.34	2.46	8,365	8,966
	700,000	2.38	2.49	8,896	9,204
	750,000	2.41	2.52	9,131	9,443
	800,000	2.44	2.54	9,360	9,680
	850,000	2.47	2.57	9,598	9,810
	900,000	2.49	2.60	9,837	10,160
	1,000,000	2.54	2.65	10,277	10,589
	1,250,000	2.66	2.78	11,426	12,086
	1,500,000	2.79	2.88	12,707	13,017
	1,750,000	2.90	2.98	13,778	14,090
	2,000,000	3.02	3.10	15,243	15,510
138,000 grounded)	4/0	2.18	2.32	6,686	7,231
	250,000	2.21	2.37	6,821	7,674
	300,000	2.25	2.41	7,239	8,059
	350,000	2.29	2.44	7,514	8,334
	400,000	2.33	2.47	7,750	8,541
	450,000	2.38	2.50	8,171	8,765
	500,000	2.42	2.53	8,436	8,963
	600,000	2.47	2.60	8,908	9,403
	650,000	2.51	2.62	9,146	9,643
	700,000	2.54	2.64	9,665	10,128

Above data are approximate and subject to normal manufacturing tolerances.

Diameters and Weights of Oil-filled, Paper-insulated, Single-conductor, Concentric-stranded, Hollow-core Cable (*Continued*)

Rated voltage, phase to phase	Size, A.w.g. or cir. mils	Over-all diam., in.		Weight, lb. per 1,000 ft.	
		Core i.d. = 0.50 in.	Core i.d. = 0.69 in.	Core i.d. = 0.50 in.	Core i.d. = 0.69 in.
	750,000	2.57	2.69	9,919	10,717
	800,000	2.60	2.71	10,168	10,941
	850,000	2.63	2.75	10,418	11,205
	900,000	2.65	2.77	10,682	11,441
	1,000,000	2.72	2.82	11,492	11,918
	1,250,000	2.84	2.94	12,688	13,105
	1,500,000	2.95	3.06	13,531	14,580
	1,750,000	3.07	3.15	15,028	15,492
	2,000,000	3.18	3.26	16,061	16,557
161,000 (grounded)	250,000	2.41	2.55	7,948	8,512
	300,000	2.45	2.59	8,234	8,790
	350,000	2.49	2.62	8,495	9,047
	400,000	2.52	2.65	8,775	9,293
	450,000	2.56	2.70	9,037	9,890
	500,000	2.60	2.73	9,293	10,136
	600,000	2.65	2.79	9,807	10,630
	650,000	2.71	2.81	10,385	10,871
	700,000	2.74	2.84	10,631	11,225
	750,000	2.76	2.87	10,880	11,361
	800,000	2.80	2.90	11,130	11,582
	850,000	2.83	2.93	11,383	11,846
	900,000	2.85	2.95	11,644	12,300
	1,000,000	2.90	3.02	12,111	13,175
	1,250,000	3.04	3.13	13,878	14,076
	1,500,000	3.15	3.24	14,787	15,155
	1,750,000	3.25	3.35	15,929	16,704
	2,000,000	3.38	3.45	17,459	17,802
230,000 (grounded)	600,000	....	3.38	.....	14,167
	1,000,000	....	3.59	.....	16,335
	2,000,000	....	3.83	.....	21,342

Above data are approximate and subject to normal manufacturing tolerances.

157. Diameters and Weights of All-asbestos-insulated, Single-conductor Cable

(Rockbestos Products Corp.)

Size, A.w.g. or cir. mils	Stranded 600-volt power cable		Solid 600-volt rheostat wire	
	Nominal finished diam.,[a] in.	Approx. weight, lb. per 1,000 ft.	Nominal finished diam.,[a] in.	Approx. weight, lb. per 1,000 ft.
1,000,000	1.485	3,456		
950,000	1.455	3,291		
900,000	1.425	3,126		
850,000	1.395	2,961		
800,000	1.365	2,796		
750,000	1.330	2,631		
700,000	1.295	2,470		
650,000	1.260	2,307		
600,000	1.225	2,142		
550,000	1.185	1,977		
500,000	1.145	1,812		
450,000	1.105	1,647		
400,000	1.060	1,482		
350,000	1.015	1,317		
300,000	0.960	1,219		
250,000	0.905	982		
4/0	0.800	819	0.670	765
3/0	0.740	672	0.620	624
2/0	0.690	555	0.575	481
1/0	0.645	462	0.535	392
1	0.605	388	0.500	322
2	0.505	274	0.430	250
3	0.470	227	0.400	205
4	0.445	188	0.375	170
5	0.420	157	0.355	141
6	0.395	132	0.335	118
8	0.320	87	0.300	85
10	0.290	63	0.275	60
12	0.265	48	0.255	46
14	0.245	38	0.235	36
16	0.230	31	0.225	30
18	0.215	26	0.210	26

All conductors covered with asbestos braid over insulation.

Finished diameters given above are average. A tolerance of plus or minus 5 per t is necessary, owing to variations in process of manufacture.

158. Diameters and Weights of Asbestos Varnished-cambric-insulated, Single-conductor Cable

(Rockbestos Products Corp.)

Size, A.w.g. or cir. mils	600-volt cable		1,000-volt cable		2,000-volt cable		3,000-volt cable		5,000-volt cable		8,000-volt cable	
	Nominal finished diam.,[a] in.	Approx. weight lb. per 1,000 ft.	Nominal finished diam.,[a] in.	Approx. weight, lb. per 1,000 ft.	Nominal finished diam.,[a] in.	Approx. weight, lb. per 1,000 ft.	Nominal finished diam.,[a] in.	Approx. weight, lb. per 1,000 ft.	Nominal finished diam.,[a] in.	Approx. weight, lb. per 1,000 ft.	Nominal finished diam.,[a] in.	Approx. weight, lb. per 1,000 ft.
1,000,000	1.465	3,510	1.475	3,521	1.505	3,558	1.565	3,635	1.625	3,721	1.755	4,309
950,000	1.435	3,346	1.445	3,354								
900,000	1.405	3.182	1.415	3,187	1.445	3,230	1.505	3,302	1.565	3,379	1.695	3,955
850,000	1.375	3,018	1.385	3,020								
800,000	1.345	2,854	1.355	2,853	1.385	2,907	1.445	2,969	1.505	3,040	1.635	3,601
750,000	1.310	2,689	1.320	2,687	1.350	2,738	1.410	2,800	1.470	2,876	1.600	3,047
700,000	1.275	2,524	1.285	2,521	1.315	2,569	1.375	2,631	1.435	2,701	1.565	2,870
650,000	1.240	2,359	1.250	2,355	1.280	2,403	1.340	2,457	1.400	2,532	1.530	2,693
600,000	1.205	2,193	1.215	2,189	1.245	2,236	1.305	2,293	1.365	2,362	1.495	2,516
550,000	1.165	2,027	1.175	2,023	1.205	2,066	1.265	2,119	1.325	2,190	1.455	2,339
500,000	1.125	1,860	1.135	1,857	1.165	1,897	1.225	1,955	1.285	2,018	1.415	2,162
450,000	1.085	1,692	1.095	1,691	1.125	1,728	1.185	1,786	1.245	1,844	1.375	1,985
400,000	1.040	1,525	1.050	1,525	1.080	1,564	1.140	1,612	1.200	1,674	1.330	1,808
350,000	0.995	1,357	1.005	1,359	1.035	1,390	1.095	1,443	1.155	1,500	1.285	1,631
300,000	0.940	1,188	0.950	1,193	0.980	1,225	1.040	1,269	1.100	1,324	1.230	1,452
250,000	0.885	1,017	0.895	1,024	0.925	1,060	0.985	1,094	1.045	1,153	1.175	1,277
4/0	0.780	839	0.810	857	0.840	878	0.900	920	0.960	967	1.080	1,069
3/0	0.720	690	0.750	708	0.780	715	0.840	766	0.900	812	1.020	908
2/0	0.670	571	0.700	588	0.730	594	0.790	642	0.850	687	0.970	777
1/0	0.625	476	0.655	491	0.685	492	0.745	543	0.805	582	0.925	671

Diameters and Weights of Asbestos Varnished-cambric-insulated, Single-conductor Cable (*Continued*)

Size, A.w.g. or cir. mils	600-volt cable		1,000-volt cable		2,000-volt cable		3,000-volt cable		5,000-volt cable		8,000-volt cable	
	Nominal finished diam.,[a] in.	Approx. weight, lb. per 1,000 ft.	Nominal finished diam.,[a] in.	Approx. weight, lb. per 1,000 ft.	Nominal finished diam.,[a] in.	Approx. weight, lb. per 1,000 ft.	Nominal finished diam.,[a] in.	Approx. weight, lb. per 1,000 ft.	Nominal finished diam.,[a] in.	Approx. weight, lb. per 1,000 ft.	Nominal finished diam.,[a] in.	Approx. weight, lb. per 1,000 ft.
1	0.585	371	0.615	413	0.645	412	0.705	459	0.765	497	0.885	580
2	0.505	287	0.535	299	0.585	324	0.645	383	0.705	402	0.835	500
3	0.470	238	0.500	250	0.550	269	0.610	331	0.670	363	0.800	443
4	0.445	198	0.475	209	0.525	233	0.585	260	0.645	319	0.775	395
5	0.420	166	0.450	176	0.500	197	0.560	225	0.620	285	0.750	358
6	0.395	141	0.425	151	0.475	172	0.535	195	0.595	251	0.725	330
8	0.360	100	0.390	109	0.440	130	0.500	155	0.560	182	0.690	281
10	0.330	76	0.360	84	0.410	104	0.470	125	0.530	152	0.660	247
12	0.305	59	0.335	67	0.385	85	0.445	105	0.505	132		
14	0.285	46	0.315	54	0.365	70	0.425	90	0.485	117		
16	0.270	39										
18	0.255	33										

All conductors covered with asbestos braid over insulation.

[a] Finished diameters given above are average. A tolerance of plus or minus 5 per cent is necessary, owing to variations in process of manufacture.

159. Data for Nonmetallic-sheathed Building Cable
(General Cable Corp.)

Size, A.w.g.	Number of conductors	Type of conductor	Shape of cable	Approx. width or diam., in.	Approx. thickness of oval cable, in.	Ft. per coil	Approx. weight, lb. per 1,000 ft.	
							With ground wire	Without ground wire
14	2	Solid	Oval	0.590	0.330	250	108	104
14	3	Solid	Round	0.630	.....	200	175	165
14	4	Solid	Round	0.690	.....	200	352	342
12	2	Solid	Oval	0.620	0.350	200	135	125
12	3	Solid	Round	0.660	.....	200	210	200
12	4	Solid	Round	0.730	.....	200	404	394
10	2	Solid	Oval	0.670	0.370	200	175	155
10	3	Solid	Round	0.720	.....	200	270	250
10	4	Solid	Round	0.790	.....	200	497	477
8	2	7 Strand	Oval	0.920	0.510	125	260	240
8	3	7 Strand	Round	0.990	.....	125	435	400
8	4	7 Strand	Round	1.100	.....	125	922	888
6	2	7 Strand	Oval	1.010	0.560	125	410	368
6	3	7 Strand	Round	1.090	.....	125	630	576
6	4	7 Strand	Round	1.200	.....	125	1,136	1,082
4	2	7 Strand	Oval	1.110	0.610	125	560	488
4	3	7 Strand	Round	1.190	.....	125	860	776
4	4	7 Strand	Round	1.320	.....	125	1,550	1,470

160. Leaded Armored Building Cable
(Anaconda Wire and Cable Co.)

Size, A.w.g. and number of conductors	Thickness of rubber, in.	Thickness of lead, in.	Approx. over-all diam., in.	Approx. weight, lb. per 1,000 ft.
14/2	3/64	3/64	0.620	435
14/3	3/64	3/64	0.650	690
12/2	3/64	3/64	0.655	480
12/3	3/64	3/64	0.700	760
10/2	3/64	3/64	0.710	640
10/3	3/64	3/64	0.745	840
8/2	3/64	3/64	0.830	960
8/3	3/64	3/64	0.870	1,325
6/2	3/64	3/64	0.995	1,190
6/3	3/64	3/64	1.050	1,590
4/3	3/64	3/64	1.185	2,210

161. Nonleaded Solid Armored Building Cable
(Anaconda Wire and Cable Co.)

Size, A.w.g., and no. of conductors	Diam. of wire, in.	Thickness of rubber, in.	Approx. over-all diam., in.	Approx. weight, lb. per 1,000 ft.
14/1	0.064	3/64	0.375	140
14/2	0.064	3/64	0.540	260
14/3	0.064	3/64	0.570	296
14/4	0.064	3/64	0.615	332
12/1	0.081	3/64	0.395	156
12/2	0.081	3/64	0.575	288
12/3	0.081	3/64	0.605	337
12/4	0.081	3/64	0.655	406
10/1	0.102	3/64	0.415	179
10/2	0.102	3/64	0.615	336
10/3	0.102	3/64	0.645	408
10/4	0.102	3/64	0.740	586
8/1	0.128	4/64	0.465	240
8/2	0.128	4/64	0.785	540
8/3	0.128	4/64	0.830	650
6/1	0.162	4/64	0.530	285

162. Nonleaded Stranded Armored Building Cable
(Anaconda Wire and Cable Co.)

Size, A.w.g., and number of conductors	No. and diam. of strands, in.	Thickness of rubber, in.	Approx. over-all diam., in.	Approx. weight, lb. per 1,000 ft.
10/1	7/0.0385	3/64	0.450	192
8/1	7/0.0486	4/64	0.515	260
8/2	7/0.0486	4/64	0.770	560
8/3	7/0.0486	4/64	0.815	710
8/4	7/0.0486	4/64	0.895	830
6/1	7/0.0612	4/64	0.515	308
6/2	7/0.0612	4/64	0.890	720
6/3	7/0.0612	4/64	0.945	920
6/4	7/0.0612	4/64	1.030	1,080
4/1	7/0.0772	4/64	0.565	400
4/2	7/0.0772	4/64	0.985	900
4/3	7/0.0772	4/64	1.045	1,124
4/4	7/0.0772	4/64	1.230	1.256
2/1	7/0.0974	4/64	0.635	530
2/2	7/0.0974	4/64	1.120	1,180
2/3	7/0.0974	4/64	1.260	1,500
2/4	7/0.0974	4/64	1.380	1,900
1/1	19/0.0664	5/64	0.720	720

163. Flexible Cords
(National Electrical Code)

Trade name	Type letter	Size, A.w.g.	No. of conductors	Insulation	Braid on each conductor	Outer covering	Use		
Asbestos-covered tinsel cord	AT (Note 3)	27	2 or 3	Rubber and asbestos	Cotton	None	Attached to a device	Dry places	Not hard usage
					None	Cotton or rayon			
Cotton-covered tinsel cord	CT (Note 3)	27	2 or 3	Rubber	Cotton	Cotton or rayon	Attached to a device	Dry places	Not hard usage
Rubber-jacketed tinsel cord	ATJ (Note 3)	27	2 or 3	Rubber and asbestos	None	Rubber	Attached to a device	Damp places	Not hard usage
	CTJ (Note 3)			Rubber	Cotton				
Asbestos-covered heat-resistant cord	AFC	18, 16, 14	2 or 3	Impregnated asbestos	Cotton or rayon	None	Pendant	Dry places	Not hard usage
	AFPO		2		None	Cotton, rayon, or saturated asbestos			
	AFPD		2 or 3						
Cotton-covered heat-resistant cord	CFC	18, 16, 14	2 or 3	Impregnated cotton	Cotton or rayon	None	Pendant	Dry places	Not hard usage
	CFPO		2		None	Cotton or rayon			
	CFPD		2 or 3						

Parallel cord	PO-32	18, 16	2	Rubber	Cotton	Cotton or rayon	Note 2	Dry places	Not hard usage
	PO	14 and over					Pendant or portable		
All-rubber parallel cord	POSJ-64	18	2	Rubber	None	Rubber	Pendant or portable	Damp places	Not hard usage
	POSJ-32	18, 16							
All-plastic parallel cord	POT-64	18	2	Thermoplastic	None	Thermoplastic	Pendant or portable	Damp places	Not hard usage
	POT-32	18, 16							
Lamp cord	C	18 and over	2 or more	Rubber	Cotton	None	Pendant or portable	Dry places	Not hard use
Armored cord	CA	18, 16, 14	2	Rubber	Cotton	Fibrous and metal armor	Pendant or portable	Dry places	Hard usage
Twisted portable cord	PD	18 and over	2 or more	Rubber	Cotton	Cotton or rayon	Pendant or portable	Dry places	Not hard usage
Reinforced cord	P-64	18	2 or more	Rubber	Cotton	Cotton over rubber filler	Pendant or portable	Dry places	Not hard use
	P-32	18, 16							
	P	14 and over							Hard usage
Moistureproof reinforced cord	PWP-64	18	2 or more	Rubber	Cotton	Cotton, moisture-resistant finish over rubber filler	Pendant or portable	Damp places	Not hard use
	PWP-32	18, 16							
	PWP	14 and over							Hard usage

Flexible Cords (*Continued*)

Trade name	Type letter	Size, A.w.g.	No. of conductors	Insulation	Braid on each conductor	Outer covering	Use		
Braided heavy-duty cord	K (Note 4)	18 and over	2 or more	Rubber	Cotton	Two cotton, moisture-resistant finish (Note 5)	Pendant or portable	Damp places	Hard usage
Vacuum-cleaner cord	SV	18	2	Rubber	None	Rubber	Pendant or portable	Damp places	Hard usage
	SVT			Thermoplastic		Thermoplastic			
Junior hard-service cord	SJ	18, 16	2, 3, or 4	Rubber	None	Rubber	Pendant or portable	Damp places	Hard usage
	SJO					Oil-resistant compound			
	SJT			Thermoplastic		Thermoplastic			
Hard-service cord	S (Note 6)	18 to 10, inclusive	2 or more	Rubber	None	Rubber	Pendant or portable	Damp places	Extra hard usage
	SO			Thermoplastic		Oil-resistant compound			
	ST					Thermoplastic			
	SU			90% unmilled grainless rubber	Cotton or rayon	Rubber			
	SUO					Oil-resistant compound			
Rubber-jacketed heat-resistant cord	AFSJ	18, 16	2 or 3	Impregnated asbestos	None	Rubber	Portable	Damp places	Portable heaters
	AFS	18, 16, 14							

Heater cord	HC	18, 17, 16 15, 14	2 or more	Rubber and asbestos	Cotton	None	Portable	Dry places	Portable heaters
	HPD				None	Cotton or rayon			
Rubber-jacketed heater cord	HSJ	18, 17, 16 15, 14	2 or more	Rubber and asbestos	None	Cotton and rubber	Portable	Damp places	Portable heaters
Heat- and moisture-resistant cord	AVPO	18 to 10, inclusive	2	Asbestos and varnish combined	None	Asbestos, flame-retardant moisture-resistant	Pendant or portable	Damp places	Not hard usage
	AVPD		2 or 3						
Elevator cable (See Note 9)	E	18 and over	2 or more	Rubber	Cotton	Three cotton, outer one flame-retardant and moisture-resistant (See Note 5)	Elevator lighting and control	Nonhazardous locations	
	ET	16 and over		Thermoplastic	Rayon				
	EO	18 and over		Rubber	Cotton	One cotton and a neoprene jacket (Note 5)		Hazardous locations	

NOTE 1.—Except for types AFPO, CFPO, PO-64, PO-32, PO, POSJ-64, and POSJ-32, and POT-64, POT-32, and AVPO, individual conductors are twisted together.

NOTE 2.—Type PO-64 is for use only with portable lamps, portable radio receiving appliances, portable clocks, and similar appliances that are not liable to be moved frequently and where appearance is a consideration.

NOTE 3.—Types AT, CT, ATJ, and CTJ are suitable for use in lengths not exceeding 8 ft. when attached directly, or by means of a special type of plug, to a portable appliance rated at 50 watts or less and of such a nature that extreme flexibility of the cord is essential. Types AT and ATJ are for use only with heating appliances.

NOTE 4.—Type K is suitable for use on theater stages.

NOTE 5.—Rubber-filled or varnished-cambric tapes may be substituted for the inner braids.

NOTE 6.—Types S, SO, SU, SUO, and ST are suitable for use on theater stages, in garages, and elsewhere where flexible cords are permitted by this code.

NOTE 7.—Types E and EO may have a composite assembly of steel and copper strands in the make-up of the individual conductors or may have one or more supporting fillers of cotton or hemp rope, or of cotton-covered or rubber-covered steel wire laid up with the conductors under the outer covering of the cable. In cables containing six or more conductors the steel supporting strands shall run straight through and not be cabled with the conductors.

164. Classification of Flexible Cords

(General Cable Corp.)

Type of cord	Type letters	Type of cord	Type letters
Fabric cover		Rubber-jacket covering	
Heat-resisting cords	AFC, AFPO, AFPD, CFC, CFPO, CFPD	"Mid-Rip" all-rubber parallel cord	POSJ
Parallel cotton- or rayon-covered lamp cord	PO	Rubber-jacketed cords	S, SJ
Twisted cotton- or rayon-covered lamp cord	C	Rubber-jacketed heat-resisting cords	AFS, AFSJ
Twisted portable cotton-covered cord	PD		
Reinforced cords	P, PWP	"Super Service" rubber-jacketed hard-service cord	S, SJ
Braided heavy-duty cords	K	Elevator cable	ES
Elevator cable	E	Rubber-jacketed heater cord	HSJ
Heater cords	HC, HPD		

165. Thickness of Insulation of Flexible Cords

(National Electrical Code)

Name	Type letter	Insulation	Thickness of insulation	Outer covering
Rubber-covered fixture wire—solid or stranded	RF-64	Code rubber	18 . . . . . 1/64 in.	Cotton
	RF-32	Code rubber	18–16 . . . 2/64 in.	Cotton
	RUF	90% unmilled grainless rubber	18–16 . . . 18 mils	Moisture-resistant, flame-retardant, nonmetallic
Rubber-covered fixture wire—flexible stranding	FF-64	Code rubber	18 . . . . . 1/64 in.	Cotton or rayon
	FF-32	Code rubber	18–16 . . . 2/64 in.	Cotton or rayon
	RUFF	90% unmilled grainless rubber	18–16 . . . 18 mils	Moisture-resistant, flame-retardant, nonmetallic
Thermoplastic-covered fixture wire—solid or stranded	TF	Thermoplastic	18–16 . . . 2/64 in.	None
Thermoplastic-covered fixture wire—flexible stranding	TFF	Thermoplastic	18–16 . . . 2/64 in.	None
Cotton-covered, heat-resistant fixture wire	CF	Impregnated cotton	18–14 . . . 2/64 in.	None
Asbestos-covered, heat-resistant fixture wire	AF	Impregnated asbestos	18–14 . . . 2/64 in.	None

166. Standard Nomenclature for Insulated Magnet Wire
(National Electrical Manufacturers' Association)

Description	N.E.M.A. symbol
namel wire:	
Heavy enamel	HE
Enamel	E
otton-covered wire:	
Single cotton	C
Bonded single cotton	BC
Single cotton, varnish	CV
Double cotton	DC
Bonded double cotton	BDC
Double cotton, varnish	DCV
namel- and cotton-covered wire:	
Enamel, single cotton	EC
Enamel, bonded single cotton	EBC
Enamel, single cotton, varnish	ECV
Enamel, double cotton	EDC
Enamel, bonded double cotton	EBDC
Enamel, double cotton, varnish	EDCV
Heavy enamel, single cotton	HEC
Heavy enamel, bonded single cotton	HEBC
Heavy enamel, single cotton, varnish	HECV
Heavy enamel, double cotton	HEDC
Heavy enamel, bonded double cotton	HEBDC
Heavy enamel, double cotton, varnish	HEDCV
k-covered wire:	
Single silk	S
Bonded single silk	BS
Single silk, varnish	SV
Double silk	DS
Bonded double silk	BDS
Double silk, varnish	DSV
Enamel, single silk	ES
Enamel, bonded single silk	EBS
Enamel, single silk, varnish	ESV
Enamel, double silk	EDS
Enamel, bonded double silk	EBDS
Silk-covered wire (*continued*)	
Enamel, double silk, varnish	EDSV
Heavy enamel, single silk	HES
Heavy enamel, bonded single silk	HEBS
Heavy enamel, single silk, varnish	HESV
Heavy enamel, double silk	HEDS
Heavy enamel, bonded double silk	HEBDS
Heavy enamel, double silk, varnish	HEDSV
Paper-covered wire	
Single paper	P
Single paper bonded	BP
Double paper	DP
Double paper bonded	BDP
Enamel- and paper-covered wire:	
Enamel single paper bonded	EBP
Enamel double paper bonded	EBDP
Heavy enamel, single paper bonded	HEBP
Heavy enamel, double paper bonded	HEBDP
Paper- and cotton-covered wire:	
Single paper, single cotton	PC
Single paper, double cotton	PDC
Double paper, single cotton	DPC
Double paper, double cotton	DPDC
Silk- and cotton-covered wire:	
Single cotton, single silk	CS
Single cotton, double silk	CDS
Double cotton, single silk	DCS
Double cotton, double silk	DCDS
Asbestos-covered wire:	
Asbestos covered	A
Asbestos covered, varnish treated	AV
Enamel asbestos covered	EA
Enamel asbestos covered, varnish treated	EAV

167. Space Factors[a] of Magnet-wire Insulations

(General Cable Corp.)

Wire size, A.w.g.	Standard enamel	Intermediate enamel	Heavy enamel	Enamel, single cotton	Enamel, double cotton	Enamel, single silk	Enamel, double silk	Single cotton	Double cotton	Single silk	Double silk	Asbestos
10	0.7411	0.7340	0.6992	0.6629	0.6071	.....	.....	0.6876	0.6286	.....	.....	0.6286
11	0.7358	0.7281	0.6923	0.6631	0.6066	.....	.....	0.6908	0.6448	.....	.....	0.6125
12	0.7353	0.7248	0.6916	0.6531	0.5915	.....	.....	0.6837	0.6178	.....	.....	0.5979
13	0.7315	0.7199	0.6866	0.6408	0.5743	.....	.....	0.6743	0.6026	.....	.....	0.5953
14	0 7274	0.7145	0.6816	0.6277	0.5557	.....	.....	0.6642	0.5861	.....	.....	0.5782
15	0.7256	0.7088	0.6791	0.6136	0.5363	0.6747	0.6329	0.6534	0.5686	0.7208	0.6747	0.5602
16	0.7243	0.7133	0.6749	0.6045	0.4916	0.6725	0.6259	0.6394	0.5518	0.7133	0.6627	0.5483
17	0.7204	0.7082	0.6711	0.5891	0.4995	0.6630	0.6124	0.6269	0.5289	0.7208	0.6524	0.5289
18	0.7161	0.6995	0.6648	0.5724	0.4771	0.6528	0.5975	0.6107	0.5060	0.7135	0.6383	0.5060
19	0.7084	0.6899	0.6519	0.5524	0.4523	0.6390	0.5792	0.5934	0.4825	0.7054	0.6232	0.4825
20	0.7081	0.6916	0.6489	0.5369	0.4308	0.6309	0.5659	0.5779	0.4602	0.6835	0.6103	
21	0.7040	0.6857	0.6553	0.5177	0.4068	0.6191	0.5485	0.5616	0.4371	0.6767	0.5965	
22	0.6895	0.6696	0.6411	0.5065	0.3988	0.5978	0.5231	0.5548	0.4323	0.6599	0.5737	
23	0.6963	0.6793	0.6317	0.4938	0.3797	0.5934	0.5116	0.5382	0.4094	0.6521	0.5583	
24	0.6864	0.6677	0.6267	0.4693	0.3560	0.5745	0.4879	0.5158	0.3826	0.6380	0.5373	
25	0.6755	0.6549	0.6167	0.4443	0.3255	0.5546	0.4635	0.4927	0.3556	0.6228	0.5151	
26	0.6790	0.6557	0.6128	0.4255	0.3029	0.5442	0.4459	0.4679	0.3281	0.6060	0.4914	
27	0.6677	0.6424	0.6034	0.3998	0.2772	0.5229	0.4207	0.4434	0.3019	0.5887	0.4677	
28	0.6547	0.6271	0.6013	0.3723	0.2507	0.4994	0.3934	0.4166	0.2747	0.5692	0.4418	
29	0.6627	0.6317	0.6026	0.3553	0.2318	0.4904	0.3774	0.3965	0.2532	0.5583	0.4228	

Space Factors[a] of Magnet-wire Insulations (*Continued*)

Wire size, A.w.g.	Standard enamel	Intermediate enamel	Heavy enamel	Enamel, single cotton	Enamel, double cotton	Enamel, single silk	Enamel, double silk	Single cotton	Double cotton	Single silk	Double silk	Asbestos
30	0.6490	0.6149	0.5836	0.3269	0.2065	0.4647	0.3489	0.3684	0.2270	0.5363	0.3949	
31	0.6476	0.6221	0.5751	0.3042	0.1857	0.4467	0.3266	0.3413	0.2031	0.5141	0.3681	
32	0.6344	0.6069	0.5811	0.2799	0.1659	0.3549	0.3019	0.3165	0.1824	0.4927	0.3433	
33	0.6344	0.6034	0.5611	0.2575	0.1472	0.4039	0.2795	0.2892	0.1606	0.4677	0.3156	
34	0.6183	0.5849	0.5542	0.2278	0.1281	0.3764	0.2529	0.2793	0.1404	0.4418	0.2882	
35	0.6204	0.5829	0.5327	0.2111	0.1124	0.3574	0.2321	0.2367	0.1221	0.4153	0.2618	
36	0.6042	0.5836	0.5454	0.2086	0.1046	0.3311	0.2086	0.2370	0.1144	0.3895	0.2370	
37	0.6114	0.5661	0.5454	0.1920	0.0927	0.3155	0.1920	0.2149	0.1001	0.3651	0.2149	
38	0.5937	0.5454	0.5253	0.1698	0.0791	0.2884	0.1699	0.2011	0.0858	0.3376	0.1915	
39	0.6013	0.5454	0.4969	0.1466	0.0657	0.2585	0.1466	0.1762	0.0715	0.3068	0.1665	
40	0.5824	0.5226	0.4961	0.1306	0.0569	0.2406	0.1306	0.1551	0.0601	0.2791	0.1455	
41	0.5653	0.5327	0.4750									
42	0.5836	0.5107	0.4793									
43	0.5623	0.4848	0.4520									
44	0.5454	0.4647	0.4309									

The above data are approximate and subject to normal manufacturing tolerances. Above figures are based solely upon wire dimensions and therefore apply to precision-wound coils. To obtain comparable values for random-wound coils, above figures should be multiplied by coil factors.

[a] Space factors represent the relative coil copper efficiency (multiply by 100 to obtain percentage efficiency).

168. Relative Characteristics of Different Types of Insulated Magne Wire

(General Electric Co.)

Property	E	HE	C	S	P
*Dielectric strength,[a] volts per mil:					
Mandrel	400	625	150	220	150
Layer	475	775	125	220	140
Twist	950	1,190	110	210	130
Physical properties:					
Flexibility	1	2	3	3	4
Abrasion resistance	4	3	2	1	4
Effect of elongation	1	2	2	2	3
Chemical properties:					
Resistance to mineral oil	2	2	1	1	1
Resistance to heat, °C	105	105	95	95	95
Resistance to water	1	1	[b]	[b]	[b]

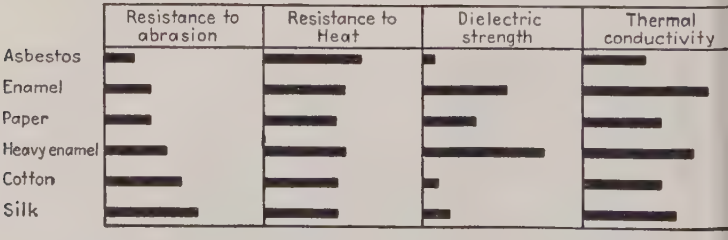
The ratings in the above table for physical and chemical properties (except resistanc to heat) are made on basic untreated magnet-wire insulations, 1 indicating the best Combinations of these basic types should be rated at the value of the lowest component

The hottest spot-temperature, expressed in degrees centigrade, indicates the rating i terms of heat resistance.

[a] These are actual dielectric-strength values.

[b] Moisture absorbing.

169. Relative Physical and Chemical Properties of Magnet Wir Insulation



170. Weights of Insulated Magnet Wire in Pounds per 1,000 Feet

(General Electric Co.)

Size, A.w.g.	Diam., in.	Plain enamel (E)	Enamel, single silk (ES)	Enamel, double silk (EDS)	Enamel, single cotton (EC)	Enamel, double cotton (EDC)	Single silk (S)	Double silk (DS)	Single cotton (C)	Double cotton (DC)
2	0.258	.....	.....	.....	.....	.....	.....	.....	203	204
3	0.229	.....	.....	.....	.....	.....	.....	.....	160	161
4	0.204	.....	.....	.....	.....	.....	.....	.....	127	127
5	0.182	.....	.....	.....	.....	.....	.....	.....	101	101
6	0.162	.....	.....	.....	.....	.....	.....	.....	80.0	80.7
7	0.144	.....	.....	.....	.....	.....	.....	.....	63.4	64.0
8	0.128	50.0	.....	.....	50.5	51.1	.....	.....	50.1	50.7
9	0.114	39.7	.....	.....	40.2	40.7	.....	.....	39.9	40.4
10	0.102	31.8	.....	.....	32.3	32.5	.....	.....	32.0	32.3
11	0.0907	25.2	.....	.....	25.6	25.8	.....	.....	25.3	25.5
12	0.0808	20.0	.....	.....	20.4	20.6	.....	.....	20.2	20.4
13	0.072	15.9	.....	.....	16.2	16.4	.....	.....	16.0	16.2
14	0.0641	12.6	.....	.....	12.9	13.0	.....	.....	12.7	12.9
15	0.0571	10.0	.....	.....	10.3	10.5	.....	.....	10.1	10.3
16	0.0508	7.93	8.01	.....	8.18	8.31	7.89	7.96	8.06	8.17
17	0.0453	6.31	6.38	.....	6.51	6.65	6.28	6.33	6.40	6.53
18	0.0403	4.99	5.05	.....	5.17	5.28	4.97	5.03	5.08	5.19
19	0.0359	3.97	4.02	4.08	4.14	4.23	3.95	4.01	4.06	4.15
20	0.032	3.16	3.21	3.26	3.29	3.40	3.15	3.19	3.23	3.33
21	0.0285	2.51	2.56	2.60	2.63	2.73	2.51	2.55	2.57	2.67
22	0.0253	1.98	2.02	2.05	2.09	2.19	1.98	2.01	2.05	2.14
23	0.0226	1.58	1.62	1.65	1.68	1.76	1.59	1.62	1.64	1.73
24	0.0201	1.25	1.28	1.32	1.34	1.42	1.25	1.28	1.31	1.39
25	0.0179	0.993	1.02	1.05	1.06	1.15	0.997	1.03	1.03	1.12
26	0.0159	0.784	0.806	0.832	0.847	0.928	0.786	0.811	0.825	0.903
27	0.0142	0.622	0.642	0.664	0.680	0.757	0.630	0.651	0.666	0.739
28	0.0126	0.491	0.508	0.529	0.538	0.584	0.498	0.516	0.526	0.571
29	0.0113	0.396	0.412	0.430	0.441	0.485	0.403	0.420	0.430	0.473
30	0.010	0.310	0.326	0.343	0.352	0.395	0.317	0.333	0.344	0.385
31	0.0089	0.246	0.261	0.277	0.278	0.327	0.253	0.269	0.273	0.317
32	0.008	0.199	0.213	0.227	0.232	0.269	0.205	0.218	0.226	0.263
33	0.0071	0.157	0.171	0.185	0.189	0.225	0.164	0.177	0.184	0.219
34	0.0063	0.124	0.136	0.148	0.152	0.183	0.130	0.142	0.147	0.178
35	0.0056	0.0980	0.109	0.121	0.125	0.156	0.105	0.116	0.121	0.151
36	0.005	0.0780	0.0880	0.0990	0.104	0.134	0.0840	0.0950	0.102	0.131
37	0.0045	0.0630	0.0730	0.0840	0.0890	0.118	0.0700	0.0833	0.0869	0.1158
38	0.004	0.0500	0.0600	0.0700	0.0760	0.100	0.0570	0.0672	0.0736	0.0970
39	0.0035	0.0380	0.0470	.....	0.0630	0.0860	0.0450	0.0542	0.0620	0.0848
40	0.0031	0.0300	0.0390	.....	0.0550	0.0780	0.0370	0.0460	0.0539	0.0763
41	0 0028	0.0250								
42	0.0025	0.0197								

171. Nominal Diameters (in Mils) of Magnet Wire

(General Electric Co.)

Size, A.w.g.	Bare	Plain enamel (G)	Heavy enamel (HE)	Enamel single silk (ES)	Enamel double silk (EDS)	Enamel single cotton (EC)	Enamel double cotton (EDC)	Heavy-enamel single cotton (HEC)	Heavy enamel double cotton (HEDC)	Single silk (S)	Double silk (DS)	Single cotton (C)	Double cotton (DC)	Formex wire
2	258	.....	.....	....	....	.....	.....	.....	.....	....	....	266	274	
3	229	.....	.....	....	....	.....	.....	.....	.....	....	....	237	245	
	220	.....	.....	....	....	.....	.....	.....	.....	....	....	228	236	
4	204	.....	.....	....	....	.....	.....	.....	.....	....	....	212	220	
	193	.....	.....	....	....	.....	.....	.....	.....	....	....	201	209	
5	182	.....	.....	....	....	.....	.....	.....	.....	....	....	190	198	
	172	.....	.....	....	....	.....	.....	.....	.....	....	....	180	188	
6	162	.....	.....	....	....	.....	.....	.....	.....	....	....	170	176	
	153	.....	.....	....	....	.....	.....	.....	.....	....	....	161	167	
7	144	.....	.....	....	....	.....	.....	.....	.....	....	....	152	158	
	134	.....	.....	....	....	.....	.....	.....	.....	....	....	142	148	
8	128	130	132	....	....	.....	.....	.....	.....	....	....	136	142	132
	120	122	124	....	....	.....	.....	.....	.....	....	....	128	134	124
9	114	116	118	....	....	.....	.....	.....	.....	....	....	121	126	118
	109	111	113	....	....	.....	.....	.....	.....	....	....	116	121	113
10	102	104	106	....	....	110	115	112	117	....	....	108	113	106
	95.0	96.8	98.5	....	....	103	108	105	110	....	....	101	106	98.5
11	90.7	92.5	94.1	....	....	97.5	102	99.1	104	....	....	95.7	100	94.1
	86.0	87.8	89.4	....	....	92.8	97.3	94.1	98.9	....	....	91.0	95.5	89.4
12	80.8	82.5	84.0	....	....	87.5	92.0	89.0	93.5	....	....	85.8	90.3	84.0
	76.0	77.7	79.2	....	....	82.7	87.2	84.2	88.7	....	....	81.0	85.5	79.2
13	72.0	73.7	75.1	....	....	78.7	83.2	80.1	84.6	....	....	77.0	81.5	75.1
	68.0	69.7	71.1	....	....	74.7	79.2	76.1	80.6	....	....	73.0	77.5	71.1
14	64.1	65.8	67.1	....	....	70.8	75.3	72.1	76.6	....	....	69.1	73.6	67.1
	61.0	62.7	64.0	....	....	67.7	72.2	69.0	73.5	....	....	66.0	70.5	64.0
15	57.1	58.7	60.0	60.7	62.7	63.7	68.2	65.0	69.5	59.1	61.1	62.1	66.6	60.0
	54.0	55.6	56.9	57.6	59.6	60.6	65.1	61.9	66.4	56.0	58.0	59.0	63.5	56.9

16	50.8	52.3	53.7	54.3	56.3	57.3	61.8	58.7	63.2	52.8	54.8	55.8	60.3	53.7
	49.0	50.5	51.9	52.5	54.5	55.5	60.0	56.9	61.4	51.0	53.0	54.0	58.5	51.9
17	45.3	46.8	48.1	48.8	50.8	51.8	56.3	53.1	57.6	47.3	49.3	50.3	54.8	48.1
	42.0	43.5	44.8	45.5	47.5	48.5	53.0	49.8	54.3	44.0	46.0	47.0	51.5	44.8
18	40.3	41.7	43.0	43.7	45.7	46.7	51.2	48.0	52.5	42.3	44.3	45.3	49.8	43.0
	38.5	39.9	41.2	41.9	43.9	44.9	49.4	46.2	50.7	40.5	42.5	43.5	48.0	41.2
19	35.9	37.3	38.5	39.3	41.3	42.3	46.8	43.5	48.0	37.9	39.9	40.9	45.4	38.5
20	32.0	33.3	34.5	35.3	37.3	38.3	42.8	39.5	44.0	34.0	36.0	37.0	41.5	34.5
	30.5	31.8	33.0	33.8	35.8	36.8	41.3	38.0	42.5	32.5	34.5	35.5	40.0	33.0
21	28.5	29.8	30.9	31.8	33.8	34.8	39.3	35.9	40.4	30.5	32.5	33.5	38.0	30.9
22	25.3	26.5	27.6	28.5	30.5	31.0	35.0	32.1	36.1	27.3	29.3	29.8	33.8	27.6
23	22.6	23.7	24.8	25.7	27.7	28.2	32.2	29.3	33.3	24.6	26.6	27.1	31.1	24.8
24	20.1	21.2	22.2	23.2	25.2	25.7	29.7	26.7	30.7	22.1	24.1	24.6	28.6	22.2
25	17.9	19.0	19.9	21.0	23.0	23.5	27.5	24.4	28.4	19.9	21.9	22.4	26.4	19.9
26	15.9	16.9	17.8	18.9	20.9	21.4	25.4	22.3	26.3	17.9	19.9	20.4	24.4	17.8
27	14.2	15.2	16.0	17.2	19.2	19.7	23.7	20.5	24.5	16.2	18.2	18.7	22.7	16.0
28	12.6	13.5	14.3	15.5	17.5	18.0	22.0	18.8	22.8	14.6	16.6	17.1	21.1	14.3
29	11.3	12.2	12.9	14.2	16.2	16.7	20.7	17.4	21.4	13.3	15.3	15.8	19.8	12.9
30	10.0	10.8	11.5	12.8	14.8	15.3	19.3	16.0	20.0	12.0	14.0	14.5	18.5	11.5
31	8.9	9.6	10.4	11.6	13.6	14.1	18.1	14.9	18.9	10.9	12.9	13.4	17.4	10.4
32	8.0	8.7	9.4	10.7	12.7	13.2	17.2	13.9	17.9	10.0	12.0	12.5	16.5	9.4
33	7.1	7.7	8.4	9.7	11.7	12.2	16.2	12.9	16.9	9.1	11.1	11.6	15.6	8.4
34	6.3	6.9	7.4	8.9	10.9	11.4	15.4	11.9	15.9	8.3	10.3	10.8	14.8	7.4
35	5.6	6.1	6.6	8.1	10.1	10.6	14.6	11.1	15.1	7.6	9.6	10.1	14.1	6.6
36	5.0	5.5	5.9	7.5	9.5	9.5	13.5	9.9	13.9	7.0	9.0	9.0	13.0	5.9
37	4.5	4.9	5.4	6.9	8.9	8.9	12.9	9.4	13.4	6.5	8.5	8.5	12.5	5.4
38	4.0	4.4	4.8	6.4	8.4	8.8	12.8	8.8	12.8	6.0	8.0	8.0	12.0	4.8
39	3.5	3.8	4.2	5.8	7.8	7.8	11.8	8.2	12.2	5.5	7.5	7.5	11.5	4.2
40	3.1	3.4	3.8	5.4	7.4	7.4	11.4	7.8	11.8	5.1	7.1	7.1	11.1	3.8
41	2.8	3.1	3.4	....	....	.....	.....	.....	.....	....	....	.....	.....	3.4
42	2.5	2.8	3.0	....	....	.....	.....	.....	.....	....	....	.....	.....	3.0

NOTE.—These diameters are subject to variation due to variations in copper, enamel, silk, and cotton. The copper may vary plus or minus 1 per cent in diameter on 0.010 in. and larger and plus or minus 0.0001 in. on smaller sizes; enamel may vary from minus 15 per cent to plus 35 per cent from the nominal; cotton, minus 15 per cent, plus 0; and silk, minus 40 per cent, plus 0 (these tolerances for enamel, cotton, and silk are approximate). The nominal addition for the insulation is obtained by subtracting the nominal bare from the nominal insulated diameter.

172. Feet per Pound of Magnet Wire

(General Electric Co.)

Size, A.-w.g.	Diam., in.	Plain enamel (E)	Enamel, single silk (ES)	Enamel, double silk (EDS)	Enamel, single cotton (EC)	Enamel, double cotton (EDC)	Single silk (S)	Double silk (DS)	Single cotton (C)	Double cotton (DC)
2	0.258	.....	.....	.....	.....	.....	.....	.....	4.93	4.90
3	0.229	.....	.....	.....	.....	.....	.....	.....	6.25	6.21
4	0.204	.....	.....	.....	.....	.....	.....	.....	7.89	7.83
5	0.182	.....	.....	.....	.....	.....	.....	.....	9.93	9.85
6	0.162	.....	.....	.....	.....	.....	.....	.....	12.5	12.4
7	0.144	.....	.....	.....	.....	.....	.....	.....	15.8	15.6
8	0.128	20.0	.....	.....	19.8	19.6	.....	.....	20.0	19.7
9	0.114	25.2	.....	.....	24.9	24.6	.....	.....	25.1	24.8
10	0.102	31.5	.....	.....	31.0	30.8	.....	.....	31.3	31.1
11	0.0907	39.8	.....	.....	39.1	38.8	.....	.....	39.5	39.2
12	0.0808	50.0	.....	.....	49.0	48.6	.....	.....	49.6	49.1
13	0.072	62.9	.....	.....	61.6	61.0	.....	.....	62.4	61.8
14	0.0641	79.6	.....	.....	77.6	76.7	.....	.....	78.8	77.8
15	0.0571	99.9	.....	.....	99.7	95.7	.....	.....	98.6	97.2
16	0.0508	126	125	.....	122	120	127	125.63	124	122
17	0.0453	158	157	.....	154	150	159	157.98	156	153
18	0.0403	200	198	.....	193	189	201	198.81	197	193
19	0.0359	252	249	245	242	236	253	249.38	246	241
20	0.032	316	312	307	304	294	317	313.48	310	300
21	0.0285	398	391	385	380	366	398	392	389	375
22	0.0253	505	495	488	478	457	505	498	488	467
23	0.0226	633	617	606	595	568	629	617	610	578
24	0.0201	800	781	758	746	704	800	781	763	719
25	0.0179	1,010	980	952	943	870	1,000	971	971	893
26	0.0159	1,280	1,240	1,200	1,180	1,080	1,270	1,233	1,210	1,110
27	0.0142	1,610	1,560	1,510	1,470	1,320	1,590	1,536	1,500	1,350
28	0.0126	2,040	1,970	1,890	1,860	1,710	2,010	1,938	1,900	1,750
29	0.0113	2,530	2,430	2,330	2,270	2,060	2,480	2,381	2,330	2,110
30	0.010	3,230	3,070	2,920	2,840	2,530	3,160	3,003	2,910	2,600
31	0.0089	4,070	3,830	3,610	3,600	3,060	3,950	3,717	3,660	3,160
32	0.008	5,030	4,700	4,410	4,310	3,720	4,880	4,590	4,430	3,800
33	0.0071	6,370	5,850	5,410	5,290	4,440	6,100	5,650	5,440	4,570
34	0.0063	8,070	7,350	6,760	6,580	5,460	7,690	7,040	6,800	5,620
35	0.0056	10,200	9,170	8,260	8,000	6,410	9,520	8,620	8,260	6,620
36	0.005	12,800	11,400	10,100	9,620	7,460	11,900	10,500	9,800	7,630
37	0.0045	15,900	13,700	11,900	11,200	8,480	14,300	12,000	11,500	8,640
38	0.004	20,000	16,700	14,300	13,200	9,000	17,500	14,900	13,600	10,300
39	0.0035	26,300	21,300	.....	15,900	11,600	22,200	18,500	16,100	11,800
40	0.0031	33,300	25,600	.....	18,200	12,800	27,000	21,700	18,600	13,100
41	0.0028	40,000								
42	0.0025	50,800								

(Driver-Harris Co.)

Material	Specific resistance at 20°C. (68°F.)		Temperature coefficient of resistance		Coefficient of linear expansion		Specific heat, g.-cal.	Thermal conductivity, watts per cm. °C.	Approx. melting point, °C.	Tensile strength at 20°C., per sq. in.		Specific gravity	Weight, lb. per cu. in.
	Microhm per cu. cm.	Ohms per cir. mil-ft.	Temp. coeff.	Diff. in temp., °C.	Coeff. of exp.	Diff. in temp. °C.				Max.	Min.		
Driver-Harris Alloys:													
Ohmax	167	1000	−0.00035	20–500	0.0000156	20–1000	.....	.....	1,500	200,000	125,000	6.80	0.246
Radiohm	133	800	0.0007	20–500	0.0000155	20–1000	.....	.....	.....	175,000	90,000	7.30	0.263
Nichrome	112	675	0.00017	20–100	0.000017	20–1000	0.107	0.136	1,350	175,000	95,000	8.247	0.2979
Nichrome V	108	650	0.00013	20–100	0.000017	20–1000	0.104	0.149	1,400	200,000	100,000	8.412	0.3039
525 Alloy	100	600	0.00034	20–500	0.0000151	20– 500	0.110	0.130	1,380	150,000	70,000	7.99	0.288
Nirex	98.1	590	0.000125	20–500	0.0000161	20– 750	0.109	0.136	1,388	175,000	80,000	8.55	0.3089
Comet	95	570	0.00088	20–500	0.000015	20– 500	0.114	0.135	1,480	160,000	75,000	8.15	0.294
Nilvar	80.5	484	.....	.....	0.000001	20– 100	0.123	0.110	1,425	150,000	70,000	8.08	0.292
D-H-Nirosta	73	438	0.00094	20–500	0.000020	20–1000	0.117	0.200	1,399	300,000	100,000	7.93	0.286
42 Alloy	66.5	400	0.0012	20–500	0.0000053	20– 400	.....	.....	1,425	150,000	70,000	8.12	0.293
52 Alloy	43.2	260	0.0029	20–500	0.0000095	20– 450	.....	.....	1,425	150,000	70,000	8.247	0.2979
Advance	49	294	±0.0002	20–100	0.0000149	20– 100	0.094	0.218	1,210	135,000	60,000	8.9	0.321
Manganin	48.2	290	±0.000015	15– 35	0.0000187	15– 35	.....	.....	1,020	90,000	40,000	8.192	0.296
Lucero	48.2	290	0.0010	20–250	0.0000125	20– 100	0.127	0.250	1,350	150,000	70,000	8.19	0.296
Filmetal D	41.5	250	0.00179	20–400	0.0000143	20– 500	.....	.....	1,450	175,000	95,000	8.590	0.3103
Midohm	30	180	0.00018	20–100	0.0000175	20– 500	.....	.....	1,100	100,000	50,000	8.9	0.321
R-63 Alloy	25	150	0.0027	20–250	0.0000152	20– 500	0.126	0.385	1,425	175,000	70,000	8.72	0.315
Hytemco	20	120	0.0045	20–100	0.000015	20–1000	0.125	0.289	1,425	150,000	70,000	8.46	0.305
Magno	20	120	0.0036	20–100	0.0000143	20– 500	0.127	0.271	1,435	135,000	60,000	8.750	0.316

Properties of Metals and Alloys for Resistance Wires (*Continued*)

Material	Specific resistance at 20°C. (68°F.)		Temperature coefficient of resistance		Coefficient of linear expansion		Specific heat, g.-cal.	Thermal conductivity, watts per cm. °C.	Approx. melting point, °C.	Tensile strength at 20°C., per sq. in.		Specific gravity	Weight, lb. per cu. in.
	Microhm per cu. cm.	Ohms per cir. mil-ft	Temp. coeff.	Diff. in temp., °C.	Coeff. of exp.	Diff. in temp. °C.				Max.	Min.		
Manganese Nickel	14	85	0.0045	20–100	0.0000146	20– 500	0.129	0.272	1,435	135,000	60,000	8.813	0.3184
Pure Nickel	10	60	0.0050	0–100	0.000015	20– 500	0.130	0.615	1,450	135,000	60,000	8.9	0.321
Lohm	10	60	0.00071	20–100	0.000018	20– 500	.....	.....	1,100	100,000	50,000	8.9	0.321
High Brass	8.3	50	0.0016	0–100	.....	.....	.....	1.29	905	125,000	55,000	8.53	0.308
Low Brass	7.0	40	0.0071	0–100	.....	.....	.....	1 55	960	85,000	43,000	8.6	0.310
Com. Bronze	4.2	25	0.0020	0–100	.....	.....	.....	2.11	1,015	75,000	37,000	8.7	0.314
Pure Metals:													
Platinum	10.610	63.80	0.00398	.....	0.0000089	0– 20°	0.0275	0.695	1,755	.....	.....	21.45	0.7750
Iron	9.780	58.82	0.00726	.....	0.0000117	0– 20°	0.109	0.619	1,535	.....	.....	7.86	0 2840
Zinc	5.916	35.58	0.00347	.....	0.000033	0– 20°	0.0931	1.13	419.4	.....	.....	7 14	0 2579
Molybdenum	5.632	33.87	0.00479	.....	0.000005	0– 20°	0.0647	1.46	2,620	.....	.....	10.2	0.3685
Tungsten	5.523	33.22	0.00524	.....	0.000004	0– 20°	0.0336	1.60	3,370	.....	.....	19.3	0.6973
Aluminum	2.670	16.06	0.00446	.....	0.000024	0– 20°	0.2089	2.03	660	.....	.....	2.7	0.0975
Gold	2.350	14.13	0.00365	.....	0.0000142	0– 20°	0.0316	2.96	1,063	.....	.....	19.3	0.6973
Copper	1.724	10.37	0.00393	.....	0.0000166	0– 20°	0.0951	3.88	1,083	.....	.....	8.92	0.3223
Silver	1.622	9.755	0.00361	.....	0.0000189	0– 20°	0.0559	4.19	960	.....	.....	10.5	0.3793

174. Electrical resistance wire is wire that has the characteristic of high resistance to the flow of electric current. It is this higher resistance characteristic which distinguishes resistance wire from conducting wire. The material used for conducting wires should have as low a resistance as possible. Electrical resistance wire is used for the wiring of rheostats, resistors, heaters, furnaces, electric ranges, etc. Metal alloys are used for the manufacture of resistance wires. The more common alloys employed are nickel chromium, nickel copper, nickel chromium iron, nickel iron, and manganese nickel. In Table 173 are listed the properties of metals and alloys manufactured by the Driver-Harris Co. for resistance wire. Although the table gives the trade names for the one company, it will be found to be fairly representative for the alloys of the other manufacturers.

CABLE JOINTS AND TERMINAL CONNECTIONS

175. Cable joints and connections are an essential part of any electric circuit. It is of utmost importance that they be properly made, since any system is only as strong as its weakest link. The basic requirements of any joint or connection are that it shall be both mechanically and electrically as strong as the cable with which it is used. High-quality workmanship and materials must be employed so that permanently good electrical contact and insulation (if required) will be ensured. The more common satisfactory methods of making joints and connections in electric cables are discussed in the following sections.

176. Joints and Connections for Insulated Cables.—There are two methods of making joints or connections for insulated cables: by means of soldered connections and by means of solderless connection devices (see Sec. **233**). Soldered connections were the old accepted standard, but in the past few years solderless splicing devices and connectors have gained wide favor for low-voltage work. The use of such devices materially reduces the amount of time required for the making of splices and terminal lug connections. Moreover, if the device is of good design, in addition to the mechanical strength of the connection being fully as great as that of a good soldered connection, the solderless connection has the advantage that the electrical contact will not fail under short circuits or continuous overloads due to the melting of solder.

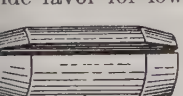


FIG. 6.—Split copper cable connecting sleeve.

Soldered joints may be made by means of soldered splices (see Secs. **34** to **204**) or by a copper sleeve (see Fig. 6 and Sec. **205**) thoroughly sweated to the cable.

177. Insulation of Joints.—Every joint in insulated cable must be covered with insulation equivalent in insulating properties to that on the cable itself. Soldered joints in rubber-insulated cables are insulated with rubber tape. The rubber employed is a self-vulcanizing rubber tape often

referred to as splicing gum. Different rubber tapes are available made from different types of rubber compound. One type is made from normal-aging compound and may be used for cables insulated with Code, intermediate, A.S.T.M. 30 per cent Class AO, or performance rubber compounds. A better grade of tape having better aging, heat-resisting, and moisture-resisting properties was developed for performite-compound-insulated cables. It may be used for high-grade joints in any type of rubber-insulated cables. For insulating joints in cables insulated with an oil-base compound (corona and ozone resisting) a corona-resisting tape made from an oil-base compound should be used.

Soldered joints in varnished-cambric- and paper-insulated cables are insulated with varnished-cambric tape.

Joints made with solderless connectors may be insulated as described above for soldered joints, or an insulating cover may be employed.

Refer to Secs. **207** and **208** for more detailed instructions for application of insulating tapes.

178. Protection of Joints.—Some form of protection should be supplied over the insulating tape of a joint. For all types of braided cables the joint is protected by applying two layers of friction tape over the insulated joint. Friction tape is made of closely woven cotton fabric treated on both sides with a rubber compound of adhesive character.

179. Completed Joints.—Cross-sectional views of typical completed joints are shown in Figs. 7, 8, and 32 to 38.

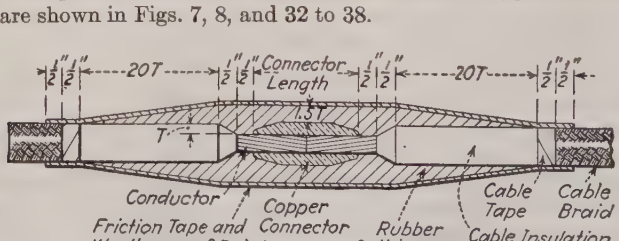


FIG. 7.—Joint in rubber-insulated, braided cable.

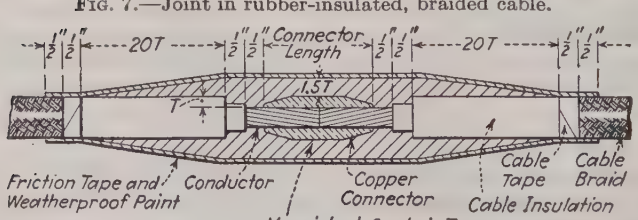


FIG. 8.—Joint in varnished-cambric-insulated, braided cable.

180. Removing Protective Covering.—For braided cable strip back the protective covering a sufficient distance from the ends of the cables to be

nted. Trim the edges with a sharp knife, taking great care not to cut e insulation or leave loose ends to get under taping.

For lead-sheathed cable proceed as follows (General Electric Co.): First, make a cut halfway through the sheath at a sufficient distance m end of cable; second, split the sheath lengthwise from the end to the t; third, tear loose the section of sheath by pulling on one edge with ers directly away from the cable axis. This will leave the remaining eath ends slightly belled in preparation for other operations. When e lead sheath is removed, be sure to remove the layer of insulation at was in contact with the lead sheath; in the case of cables employing tal shielding, the layer of insulation in contact with the shielding tal should also be removed.

181. Removing Insulation from Rubber-insulated Cables.—Com-tely remove the insulation for a distance sufficient for making the joint.

FIG. 9.—Methods of "skinning" wire.

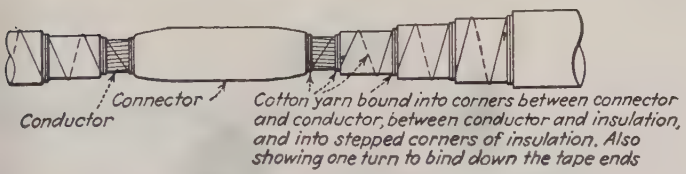


FIG. 10.—Method of stepping and binding insulation.

ver the bared conductor with a few turns of friction tape so that the nductor will not be nicked. Pencil down the conductor insulation for a tance of ½ in. (see Figs. 7 and 9). This penciling should be smooth and n and can be done best with a sharp knife, being careful not to injure conductor. All the exposed conductor insulation should then be de smooth with fine emery cloth in order to provide a good surface for application of the splicing gum. Wrap the tapered ends of the insula-n tightly with dry cotton tape, and tie the tape in place. This is to tect the insulation from scorching while the connector is being soldered he conductors.

182. Removing Insulation from Paper- or Varnished-cambric-insu-d Cable (General Electric Co.).—The cable insulation should be noved in steps as indicated in Fig. 10. For paper-insulated cable, the ps should be made by tearing the paper tapes. A convenient way to this is to hold a loop of fine steel wire (about 0.015 in. in diameter) in ce around the insulation at each step in turn, beginning with the step hest away from the end of the cable, and tear the tapes at the wire.

A weight of about 1½ lb. attached to each end of the wire will hold the loop in place while tearing the tape.

For varnished-cambric-insulated cable, the steps should be made by cutting the cloth tapes, exercising care to avoid cutting through tapes that will remain on the conductor.

It is recommended that the first step adjacent to the conductor be, in each case, about $\frac{1}{32}$ in. in height by ½ in. in length, and that the remaining steps be of equal height and spaced about ¾ in. apart. The number of steps in any case will be the same as that shown in the illustration, but the height of the steps will vary with the thickness of the insulation on the conductor.

The number of tapes to be removed for any given step must be determined by counting the total number of tape layers and measuring the

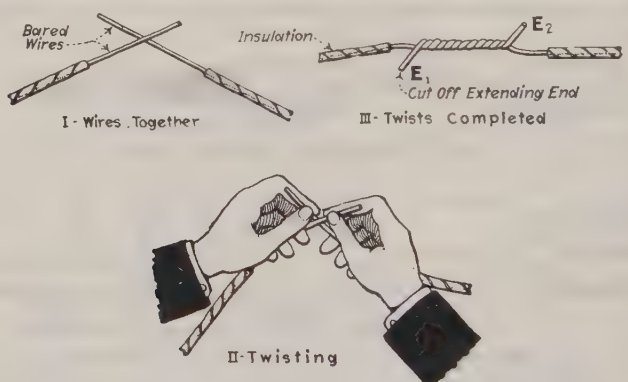
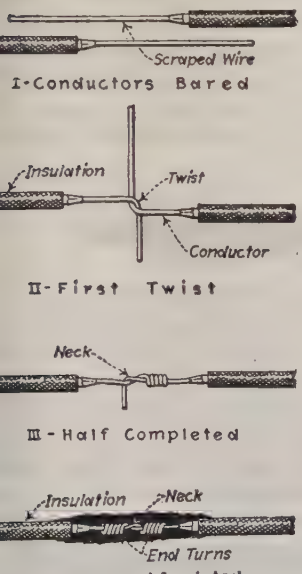


FIG. 11.—Method of forming joints in wires No. 18 and smaller.

thickness of each. The total insulation usually comprises either paper tapes varying in thickness from 0.004 to 0.008 in., or varnished-cambric tapes about 0.012 in. in thickness.

Cotton yarn should be bound into the stepped corners of the insulation and into the corners between insulation and conductor parts (Fig. 10). When doing this the following procedure should be observed: wash the exposed surfaces of stepped insulation and all metal conductor parts with high-quality Transil oil at a temperature of about 110°C. in order to remove all impurities. Dip the roll of cotton yarn in clean Transil oil at a temperature of 110°C. to remove possible moisture. Then wind the yarn in all the stepped corners of the insulation, the corners between the conductor and the insulation, and the corners between the conductor and the connector. In passing from one step of insulation to the next, bind down the tape ends with a turn of yarn. Excessive yarn should be avoided; that is, one turn in the lower steps and two in the higher steps should be sufficient.

183. Cleaning Wire Ends.—The bare wire ends should be scraped ight with the back of a knife blade or rubbed clean with sandpaper or nery cloth to ensure that the solder will adhere readily.



g. 12.—Method of preparing res for Western Union joint.

184. When splicing wires of No. 18 Brown and Sharpe gage or smaller (Fig. 11), the insulation, which is usually of paraffined cotton, is removed for a distance of about 2 in. from each wire end. Then, I, the wires should be crossed and held firmly between the thumb and fingers. Next, they should be twisted together, II, into the splice as shown at III. The projecting ends E_1 and E_2 are snipped off with the plier cutters and the whole joint is squeezed into compact form between the jaws of the pliers.

185. The Western Union joint (Fig. 12) is used more frequently than any other. It is used in interior wiring in joining two lengths of wire to extend the conductors from outlet to outlet. In outside wiring, it is used extensively. The joint is made (Fig. 12) by crossing the bared ends as shown at II and forming in them a long twist or neck (III) on either side of which five short turns should be formed as in III d IV. The pliers are employed in making a joint of this type in wires No. 8 American wire gage and smaller. For larger wires, both the ers and connectors should be used. For No. 14 es about a 3-in. length of insulation should be noved from each wire end; for No. 6 wire about n. Care should be exercised to ensure that the e ends in the completed joint are squeezed down sh with the outer short turns so that sharp ners will not cut through the tape.

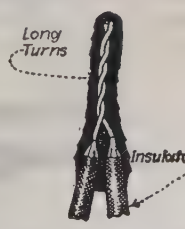


Fig. 13.—Rat-tailed joint.

186. The rat-tailed joint (Fig. 13) is often emyed in connecting lighting-fixture leads, but the nts illustrated in Figs. 14 and 15 are, usually, prefble for this purpose. It is used principally in ning conductors in outlet boxes. It is satisfactory if no longitudinal ain is impressed on it. A longitudinal strain is apt to untwist the joint.

187. The end fixture splice (Fig. 14) is used when a fixture wire, usually . 18 Brown and Sharpe gage, is to be joined to a terminating branch

conductor, which is most frequently of No. 14 gage. The larger wir is bared for about 2 in. and the fixture wire for about 3 in. Then a 2-in length of the fixture wire is wrapped around the bared No. 14 wire Next, the end of the larger wire is bent back over the joint and the remain ing portion of the fixture wire is wound about it.

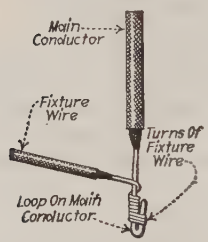


FIG. 14.—End fixture splice.

188. The back-turn splice (Fig. 15) is sometime employed instead of the fixture splice shown in Fig 14 or instead of the rat-tailed joint of Fig. 13. Thi joint (Fig. 15) will withstand considerable longitudi nal strain.

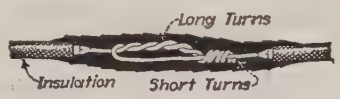


FIG. 15.—Back-turn splice.

189. The duplex joint (Fig. 16) is employed in splicing the duple conductor which is used in conduit installations. It consists of tw Western Union joints, J_1 and J_2, which should be staggered. That i they should not be opposite one another. Rubber and friction tape ar applied to each joint just as if the joint were in a single wire. Then serving of friction tape should be applied over the pair.

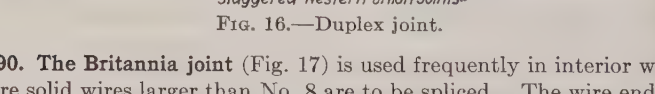


FIG. 16.—Duplex joint.

190. The Britannia joint (Fig. 17) is used frequently in interior wirin where solid wires larger than No. 8 are to be spliced. The wire ends ar bared and scraped for a distance of about 4 or 5 in. Then, the extrem end of each is bent almost to a right angle with the axis of the wir Next, a piece of bared and scraped No. 18 wire about 5 or 6 ft. long

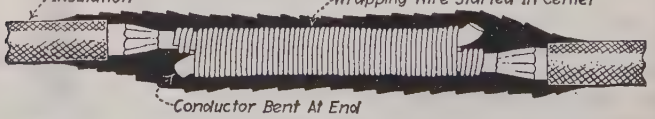


FIG. 17.—Britannia joint.

doubled on itself. Now, the large wires are held in the position whic they are to occupy in the finished splice, with a pair of connectors pliers, and the middle point of the doubled wrapping wire is placed over th center of the two large wires. Then, one bight of the wrapping wire served around the two large wires from the center to one end of the join

ıd a few finishing turns are wound on the single wire. The other bight the wrapping wire is then wound around the other portion of the joint like manner.

191. The scarf joint (Fig. 18) is utilized only for joining solid wires hen the over-all diameter of the joint must not exceed the diameter of e wire. The end of each wire is filed to a wedge shape as shown at I. ne two are laid together, and a No. 18 duplex binding wire is wound

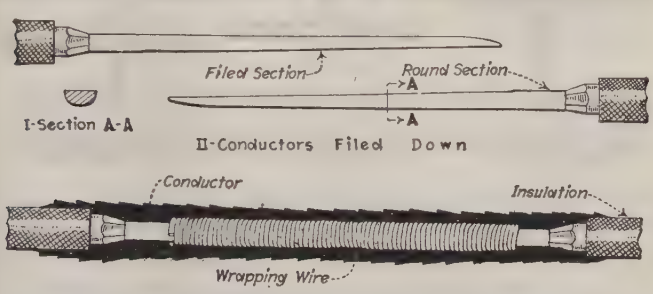


Fig. 18.—Scarf joint.

ound them. The binding wire is started in the center and is wound to ch end in the same manner as above described for the Britannia joint. few end turns of the binding wire should extend along the round mutilated portion of each large wire so that the filed-down pieces will t shift prior to soldering.

192. The ordinary tap joint (Fig. 19) is the one which is usually made in icing a tap conductor to a through conductor. It is made by wrapping

Fig. 19.—Ordinary tap joint.

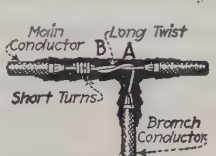


Fig. 20.—Small aerial tap.

tap wire around the main wire. Joints of this type should, preferably, wrapped as shown in Fig. 20 with long turns from *A* to *B*. Solder uld not be applied to the joint at *A*. If wrapped as in Fig. 19 or if ıpped as in Fig. 20, and if solder is applied at location *A* of the joint, it nflexible. Hence, the tap conductor is liable to be broken off if sub- ed to vibration.

193. The knotted tap joint (Fig. 21), though it is seldom used in prac- , has the advantage that the tap wire cannot untwist from the main e. It is made by bending the tap wire end into a U shape, hooking it

over the main wire, bending it over itself, and then bending the remaining bight into short turns around the main wire.

194. Cross joints (Figs. 22 and 23) may be used where it is necessary to splice a branch wire, which extends each way from the main conductor,

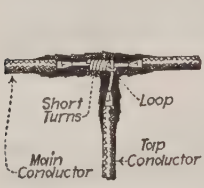


FIG. 21.—Knotted tap joint.

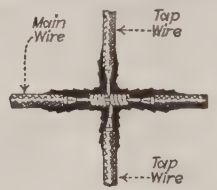


FIG. 22.—Plain cross joint.

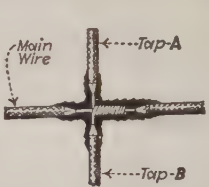


FIG. 23.—Duplex cross joint.

to the main conductor. The plain cross joint (Fig. 22) is made by wrapping two ordinary taps (Fig. 19) onto the main conductor. One tap is wound from right to left and the other from left to right.

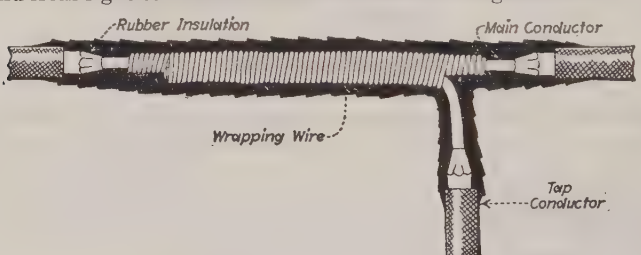


FIG. 24.—The wrapped tap joint.

195. The duplex cross joint (Fig. 23) is made by wrapping both tap wires in parallel on the main wire in the same direction.

196. The wrapped tap joint (Fig. 24) is used in interior wiring for wires of No. 6 gage and larger. It is seldom employed in outside con-

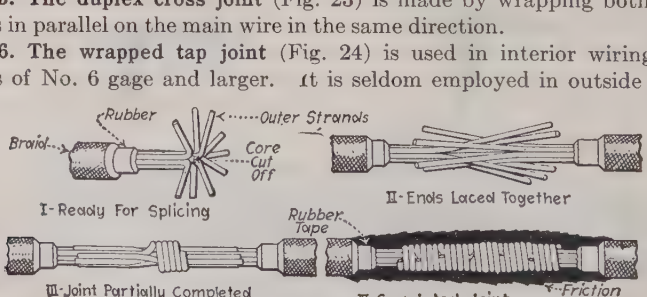


FIG. 25.—Single-wrap cable splice.

struction. It is made by bending the bared end of the tap wire into an L shape holding it along the side of and against the main wire and binding the two together as in the Britannia joint.

197. Through joints in stranded conductors or cables (Figs. 25 and 26) ay be of either of the two types illustrated. The single-wrapped joint of ig. 25 is used most frequently because of the difficulty encountered in aking a multiple-wrapped (Fig. 26) splice.

198. The single-wrapped cable splice (Fig. 25) is made as follows: irst, "skin" the ends of the two cables which are to be spliced. The end a No. 6 cable should be skinned for a distance of about 6 in.; 1/0, 8 in.; /0, 11 in.; 500,000 cir. mils, 16 in. Spread out the wires composing the

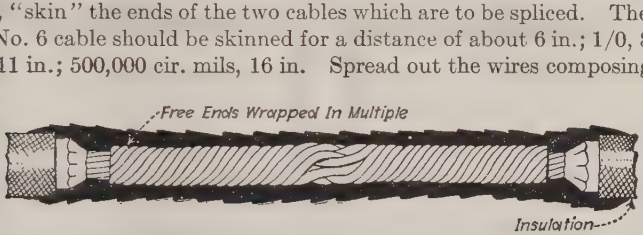
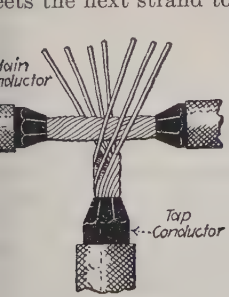


FIG. 26.—Multiple-wrap cable splice.

ble as shown at I and pull each straight and cut away the core or a few the inner wires so that the splice will not be bulky. Clean each wire th sandpaper. Force the wires back to nearly their normal positions. ce together the two ends as shown at II so that the end of each strand mes between two ends from the other cable. Wrap each free end (III) ound the main conductor and wrap similarly each strand of each con- ctor in their order going around the joint. Wrap each end around many times as it will go. Each strand should be cut off where it eets the next strand to be wrapped, as indicated at IV. The joint is, preferably, soldered by pouring, with a ladle, molten solder through and over it. Tape servings around the joint, to the thickness of the insulation on the original wire, complete the splice.



. 27.—"Fanning" of tap cables.

199. The multiple-wrapped cable splice (Fig. 26) is made in exactly the same manner as is that of Fig. 25 except that the free ends are wrapped "all together" in multiple instead of separately.

200. The multiple-wrapped cable tap is shown in Figs. 27 and 28. After the component wires have been cleaned, the strands of tap cable are equally divided into two portions and bent so that the tions form the legs of a V. The apex of the V (Fig. 27) is held inst the main cable. All the wires in one portion are wound from left right around the main conductor in multiple. The wires of the other tion are similarly wound in the other direction. The core wire, and sibly some of the inside wires, should be cut away before the wires are ned so that the splice will not be bulky.

201. The split cable tap (Fig. 29) is made in practically the same way as is the multiple-wrapped cable tap of Fig. 28, with this exception: First,

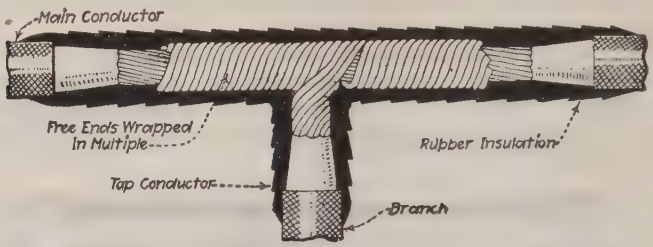


FIG. 28.—Multiple-wrap cable tap.

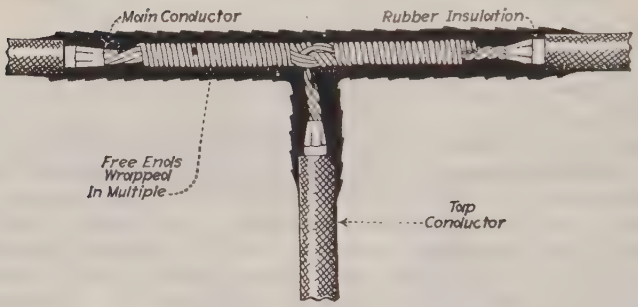


FIG. 29.—Split cable tap.

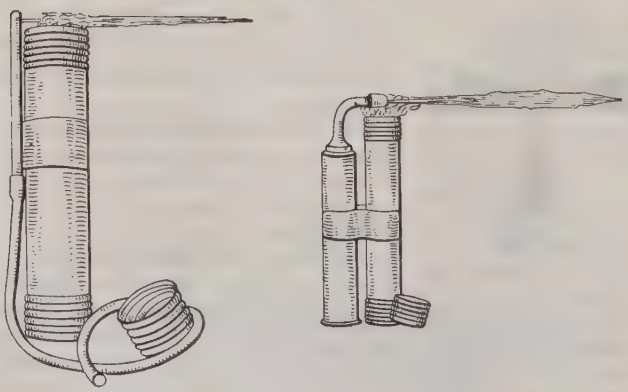


FIG. 30.—Alcohol torches.

an opening is made in the center of the bared portion of the main cable by forcing a screw driver through between its strands. Then the bared

end of the tap cable is pushed through this hole. Finally the end strands of the tap cable are "made up" around the main cable as in Fig. 29.

202. Soldering Splices in Small Wires.—Joints made by the splicing of small wires (smaller than No. 8) may be soldered with either an alcohol torch (Fig. 30) or a soldering copper. Wherever it is feasible, a soldering copper should be used. In soldering a joint with a torch, unless great care is taken, the insulation and covering of the conductors are liable to be ignited. This burning will injure the adjacent insulation and cause a thick smoke which blackens any object on which it deposits.

203. In using a soldering copper, heat it in the flame of a blowtorch. To solder the joint, the hot tool is placed under and in close contact with the joint. After the joint has become sufficiently hot to melt solder, wire solder is held against and is fed into the turns of the joint. After the solder has flowed over the entire surface of the joint the iron is removed and the joint is shaken to throw off surplus solder. With this method there is neither ignition of insulation nor sooty smoke. The soldering copper can be used in confined spaces where the use of a torch would be impossible. Wires to be soldered must always first be scraped clean and bright. Any of the commercial soldering pastes or compounds can be used as a flux.

204. Soldering Splices in Medium-sized and Large Wires.—In soldering splices in stranded wires, a plumber's fire pot may be effectively used for heating the solder. The molten solder is dipped from the pot with a ladle and poured over the splice through and around the joint until the joint becomes thoroughly hot so that the solder runs freely through the strands of the splice and thoroughly permeates the joint. Where possible the joint may be held over the plumber's fire pot during the soldering operations so that the molten solder will drain back into the pot. Where this is not possible, a second ladle should be held under the joint to catch the solder. After the joint has been uniformly heated and appears to be tinned over its entire surface, a piece of wet waste can be held on it to cool it quickly. After cooling, any sharp projections should be smoothed off with a file and fine emery cloth.

205. Soldering Joints with Split-copper Connecting Sleeves.—The connector (Fig. 6) is the split or slotted cylindrical piece that joins the two

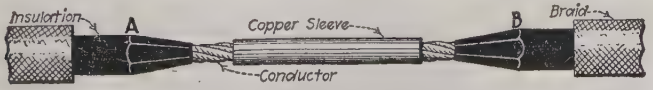


FIG. 31.—Splicing rubber-insulated conductor with copper sleeve.

conductors. If necessary, this connector may be pried open at the slot to permit placing it over the conductors, but usually it will be possible to separate the conductors a sufficient amount to permit slipping the connector over one conductor, then joining the conductors, and sliding the connector in place across both conductors so that the assembly of Fig. 31 is

produced. See that the connector is closed in maximum contact with the conductor, that it is placed concentrically on the conductors with the slot in position to receive the solder, and that the conductors are moved together, axially, until their ends butt centrally within the connector.

Before assembling the cables and connector, as described above, clean and tin the connector and conductor ends. After assembly, solder each connector solidly to its conductor by pouring hot solder over, and into, the connector, catching the excess solder in a second ladle held under the joint. The intermittent application of soldering flux will expedite soldering. When the spaces between the conductor strands and the connector are filled to overflowing with solder, fill the slot completely. Permit the solder to cool partially and, immediately prior to hardening, remove all burrs and superfluous solder by wiping with a piece of clean white tape looped around the connector and conductors. After cooling, any sharp projections should be smoothed off with a file and fine emery cloth.

206. A soldering flux removes or prevents the formation of an oxide during the operation of soldering, so that the solder will flow readily and unite firmly the members to be joined. For copper wires the following solution of zinc chloride is recommended by the Underwriters and is good: saturated solution of zinc chloride, 5 parts; alcohol, 4 parts; glycerine, 1 part. Solutions made with acids should be avoided as there is usually more or less corrosion in joints made with them. The commercial soldering pastes and sticks give good satisfaction in cleaning joints which are to be soldered.

207. Insulation of Joints in Rubber-insulated Cable.—Remove the cotton tape that was wrapped around the tapered ends of the insulation. Clean the rubber insulation with a cloth dampened with high-test gasoline and allow it to dry. The surface over which the splicing tape is to be applied should then be covered with rubber cement and the solvent allowed to evaporate until it is quite tacky. The rubber splicing tape should then be placed over the joint. Each layer should be applied smoothly and under tension so that there will be no air spaces between the layers. In putting on the first layer, start near the middle of the joint instead of at the end. The diameter of the completed insulated joint should be greater than the over-all diameter of the original cable, including the insulation. When a standard split-copper connector is used, the thickness of applied insulation over the maximum diameter of the connector should be at least 50 per cent greater than the thickness of the insulation on the original cable as indicated in Fig. 7. Most splicing tapes are self-vulcanizing, and therefore it is not necessary to vulcanize the joint later.

208. Insulation of Joints in Varnished-cambric- or Paper-insulated Cables.—Varnished-cambric tape of various widths is used for insulating these joints. One-half-inch tape is used in the spaces between the cable insulation and the connector end; ¾-in. tape is used to continue the

insulating to the original level of the cable insulation. One-inch tape is used to complete the insulation of the joint, or, in the case of joints for three-conductor, belted-type cables, the over-all of the crotch; 1-in. tape is also used either for spacing reinforced conductors, or for binding together reinforced conductors in the case of joints for 5-kv., belted-type cables.

Before applying the tape, flush all exposed surfaces of the insulation and intervening conductor parts with high quality Transil oil at 110°C. in order to remove all impurities. Also, during the application of the tape, all surfaces on which the tape is applied and each layer of tape during wrapping, should be flushed with a heavy oil compound applied at a temperature of about 20°C. with a brush that has been cleaned in high-quality Transil oil at a temperature of approximately 110°C. Tape of ½- or ¾-in. width should be applied by drawing it tightly in half-lap wrappings; 1-in. tape should be applied in butt wrappings.

The applied tape insulation should be built-up until the thickness of insulation over the maximum diameter of the connector or splice is 50 per cent greater than the thickness of the insulation on the original conductor (see Fig. 8).

209. Portable-cable Joints.—The following instructions in Secs. **210** to **223** for making joints in all-rubber portable cables have been reproduced here through the courtesy of the General Electric Co.

210. A typical single-conductor, portable-cable joint is shown in Fig. 32, and the directions to be observed in making this kind of joint are as follows, with reference to that figure:

1. Bring the cables in position for splicing, with their ends overlapping a little, and cut the cable ends off squarely.

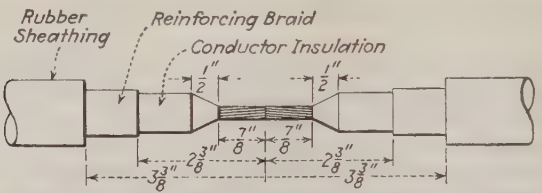
2. Remove 3⅜ in. of rubber sheathing from the end of each cable. Remove the reinforcing braid for a distance of 2⅜ in., and remove the conductor insulation for a distance of ⅞ in.

3. Pencil down the conductor insulation for a distance of ½ in. This penciling should be smooth and even, and can be done best with a sharp knife, taking care not to injure the conductor. All of the exposed conductor insulation should then be made smooth with fine emery cloth in order to provide a good surface for the application of the splicing gum, which is to be done later.

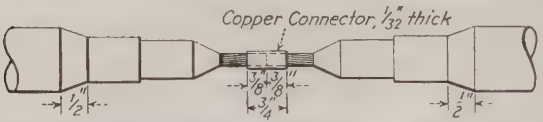
4. Wrap the tapered ends of the insulation tightly with dry cotton tape and tie the tape in place. This is to protect the insulation from scorching while the connector is being soldered to the conductors.

5. Assemble the connector in place over the conductor joint. The connector should be made of soft-drawn copper strap, ¾ in. wide and 1/32 in. thick, and long enough to wrap around the conductor without overlapping. Apply a coating of nonacid soldering flux over the surface of the conductor and then slide the connector over the conductor; let the connector slot come at the top and place it so that the two conductors

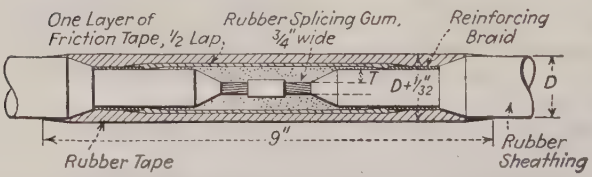
butt at the center of the connector. Pinch the connector with pliers so that it closes into maximum contact with the conductor. Solder the conductor fast to the connector by pouring hot solder over the joint until it is thoroughly heated and the solder runs freely through the slot and into



(a)-Rubber Sheathing, Reinforcing Braid, and Conductor Insulation Removed, and Conductor Insulation Penciled



(b)-Copper Connector Assembled and Rubber Sheathing Penciled



(c)-Splice Completed with Splicing Gum, Friction Tape, and Rubber Tape applied. The Joint should now be Vulcanized

TABLE OF DIMENSIONS

Conductor size, A.w.g.	Thickness of insulation, *T*, in.	Over-all diameter of cable, *D*, in.	Conductor size, A.w.g.	Thickness of insulation, *T*, in.	Over-all diameter of cable, *D*, in.
8	3/64	0.44	3	4/64	0.64
6	4/64	0.50	2	4/64	0.67
5	4/64	0.53	1	5/64	0.73
4	4/64	0.58	0	5/64	0.82

FIG. 32.—Single-conductor soldered joint in all-rubber portable cable. (*General Electric Co.*)

the strands of the cable. Solder that collects on the bottom of the connector should be brought to the top to fill the slot. Before the solder sets, wipe the connector smooth and clean with a piece of cloth. After cooling, any sharp projections should be smoothed off with a file and fine emery cloth.

6. Remove the cotton tape that was wrapped around the tapered ends of the insulation. Clean the rubber insulation with a cloth dampened with high-test gasoline, and allow it to dry. Then apply a coating of rubber cement over the entire surface on which the splicing gum is to be applied, and allow the solvent to evaporate before applying any tape.

7. Apply the splicing gum and build it up over the rubber insulation to a diameter of about $\frac{1}{16}$ in. larger than rubber insulation on the cable, as shown in Fig. 32.

8. Apply one layer of friction tape half-lapped over the splicing gum and over the ends of the reinforcing braid, as shown in Fig. 32.

9. Pencil the rubber sheathing as shown and clean the tapered surface and the outside surface of the cable for a distance of at least $\frac{3}{4}$ in. at each end with fine emery cloth and high-test gasoline, and allow to dry.

10. Cover the entire surface of the joint with a coating of rubber cement. Be sure to cover all the surface over which the final wrapping is to be applied.

11. After the solvent has evaporated, apply the rubber tape in half-lapping; build it up to a diameter of about $\frac{1}{16}$ in. greater than the diameter of the cable, and let it extend over the surface of the rubber sheathing as indicated in Fig. 32, so that the over-all length of the joint will be 9 in.

12. The joint should now be vulcanized in a suitable mold. The inside diameter of the mold should be about the same as the diameter of the cable. If a steam vulcanizer is used, a steam pressure of about 30 lb. should be applied for 15 to 30 min., depending on the size of the mold and the joint that is being vulcanized.

13. To complete the process, cover the joint with black wax and wipe it smooth.

211. Typical examples of multiconductor, portable-cable joints are shown in Figs. 33 and 34. In each case, sufficient rubber sheathing and fillers are removed from the cable ends to permit staggering the individual splices as shown in Fig. 35, in order to obtain a flexible joint of approximately the same outside diameter as the cable. The individual conductors are spliced in the same way as described for single-conductor cable. The individual joints, and the ends of the rubber-filled tape, if present, are bound with one layer of friction tape, half-lapped, as shown in the illustrations.

In order to maintain the over-all length of the joint within a given dimension it is necessary that the first splice be at a certain minimum distance from the end of the rubber sheathing. This dimension is given in the data accompanying the illustrations. The distance between the individual splices is approximately 3 in.

In splicing Type G cable, exercise care to avoid damaging the ground wires. These wires should be bent out of the way until the individual conductors are insulated.

In splicing Type SH, Class A cable, each of the single conductors must be completely shielded; *i.e.*, the copper-mesh shielding must be carried across the joint and soldered. This is shown in Fig. 34. The cable-shielding braid is removed ½ in. farther than the rubber-filled tape on each end of each conductor. The remaining braid is then opened and turned back ½ in., taking care not to loosen the braid farther than this point; such loosening is prevented by applying and soldering at this point three or four turns of tightly drawn 0.0126-in. tinned-copper wire. The ¾- by 0.015-in. flat copper braid is then applied half-lapped over the unshielded portion of the insulation. The ½ in. of cable-shielding braid, which was just turned back, is drawn over the ¾-in.-wide shielding braid, and the two shields are bound together by continuing the tightly drawn butt wraps of 0.0126-in. tinned-copper wire for a total distance of ⅞ in. The wire should then be soldered to the braid, using a nonacid soldering flux; this is necessary because there must be a positive electric contact across the joint. In applying the shield, be sure that no gaps or openings are left, since the opening in the shielding of one conductor might lead to corona.

Bring the single conductors together with approximately the same twist as the rest of the cable.

In the case of Type G cable, the ground wires should now be cut to their proper length. They should be connected in the same manner as the cable conductors, and all sharp projections removed. The bare wire must be wrapped with friction tape, half-lapped. The ground wire should then be placed in the interstices.

In jointing the shields of Type SH, Classes B, C, and D cable, follow in general the same instructions as given for Type SH, Class A; and in jointing the ground wires of Type SH, Classes C and D cable, follow the instructions for Type G cable.

Returning to the instructions for all types, the interstices are then filled and the cable made its proper shape by means of a suitable filler. The type of filler used depends on the make-up of the cable being spliced. If rubber filler is used in the cable, rubber filler should be used in the joint. If jute fillers are used in the cable, jute fillers should be used in the joint.

Rubber filler is applied by placing a coating of rubber cement over the entire surface of the individual conductors and filler space and, when the solvent has evaporated, laying strips of splicing tape longitudinally in the interstices until they are filled completely.

When jute fillers are used, the individual conductors, the jute fillers, and the ground wires, if any, should be covered completely with one layer of half-lapped friction tape. The surface of the friction tape should then be wrapped with reinforcing cord. Apply the cord in tightly drawn wraps spaced ½ in. apart, having a pitch of approximately 2 in. The joint should be wrapped first with the pitch in one direction and then with the pitch in the opposite direction, thereby obtaining the equivalent of a reinforcing braid. Tie the cord firmly at both ends.

Dimensions, in Inches, of Multiconductor Cable Joints

(See Figs. 33, 34, and 35)

Type W, 600 volts, 2-, 3-, and 4-conductor

Conductor size, A.w.g.	T	2-conductor			3-conductor			4-conductor		
		D	L	M	D	L	M	D	L	M
8	3/64	0.75	18	1/2	0.78	21	1/2	0.84	24	1/2
6	3/64	0.91			0.95			1.03		
4	4/64	1.06			1.12			1.27		
3	4/64	1.12			1.19			1.36		
2	4/64	1.19			1.31			1.42		
1	4/64	1.41			1.50			1.62		
0	5/64	1.55			1.62			1.84		

Type W, 2,500 and 3,500 volts, 3- and 4-conductor

Conductor size, A.w.g.	2,500 volts							3,500 volts						
	T	3-conductor			4-conductor			T	3-conductor			4-conductor		
		D	L	M	D	L	M		D	L	M	D	L	M
8	6/64	1.18	22	1/2	1.28	25	1/2	8/64	1.50	23	3/4	1.61	26	3/4
6	6/64	1.30			1.41				1.62			1.77		
4	6/64	1.47			1.58				1.70			1.84		
3	6/64	1.53			1.66				1.77			1.91		
2	6/64	1.59			1.76				1.88			2.03		
1	7/64	1.80			1.95				1.97			2.14		
0	7/64	1.91			2.06									

Tpye G, 2,500, 3,500, and 5,000 volts, 3-conductor

Conductor size, A.w.g.	2,500 volts				3,500 volts				5,000 volts			
	T	D	L	M	T	D	L	M	T	D	L	M
8	6/64	1.19	22	1/2	8/64	1.50	23	3/4	10/64	1.66	24	1
6	6/64	1.30			8/64	1.63			10/64	1.80		
4	6/64	1.47			8/64	1.70			10/64	1.86		
3	6/64	1.53			8/64	1.77			10/64	1.94		
2	6/64	1.59			8/64	1.87			10/64	2.03		
1	7/64	1.80			8/64	1.97			10/64	2.14		
0	7/64	1.90										

Type SH, 2,500, 3,500, and 5,000 volts, 3-conductor

Conductor size, A.w.g.	2,500 volts				3,500 volts				5,000 volts			
	T	D	L	M	T	D	L	M	T	D	L	M
8	10/64	1.66	24	1/2	11/64	1.86	25	3/4	13/64	2.00	26	1
6		1.77				2.09				2.20		
4		1.94				2.14				2.24		
3		2.04				2.21				2.33		
2		2.06				2.34				2.44		
1		2.23				2.43				2.53		
0		2.33										

Two-conductor, flat, 600 volts

Conductor size, A.w.g.	2-conductor			
	T	D	L	M
8	3/64	0.60 × 0.81	18	1/2
6	3/64	0.75 × 0.98		
4	3/64	0.84 × 1.09		
3	4/64	0.88 × 1.16		
2	4/64	0.88 × 1.29		
1	5/64	1.13 × 1.43		

The rubber sheathing should then be tapered and cleaned as described for single-conductor cable. All the surface that is to be covered with splicing gum should be covered with a coating of rubber cement. When

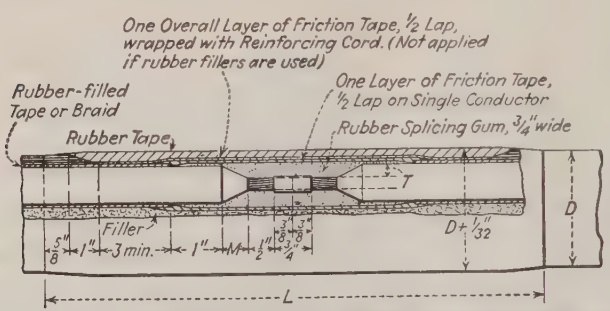


FIG. 33.—Joint for multiconductor Type W and Type G portable cable and two-conductor flat cable. (*General Electric Co.*)

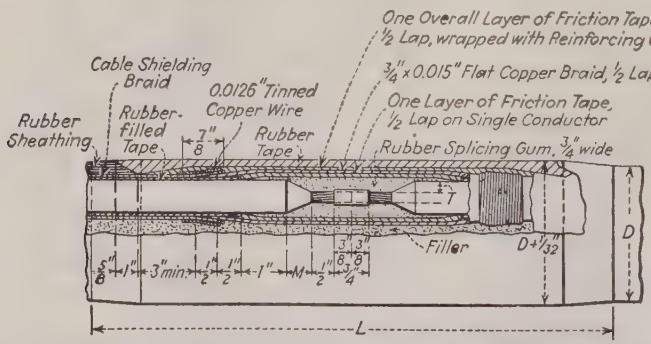


FIG. 34.—Joint for Type SH, Class A portable cable. (*General Electric Co.*)

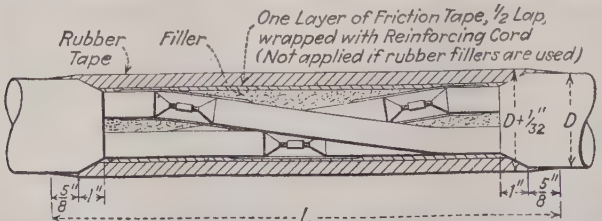


FIG. 35.—Joint for 600-volt three-conductor portable Type W cable, showing the staggering of individual splices. (*General Electric Co.*)

the solvent has evaporated, wrap the surface with splicing tape to the diameter shown in the illustrations.

The joint is now ready to be vulcanized. The same vulcanizing process is used for both shielded and nonshielded cables. Preheat the vulcanizer before inserting the joint and vulcanize according to instructions furnished with the particular vulcanizing equipment. If a steam vulcanizer is used, a steam pressure of about 30 lb. should be applied for 30 to 60 min., depending on the size of the mold and the joint that is being vulcanized. It is sometimes necessary to apply a dressing of thin paper to the mold to prevent sticking of the rubber. After vulcanizing, the joint should be covered with black wax and wiped smooth (see the instructions for vulcanizing).

Where the voltage is 2,500 or above, a feeder cable that contains provision for a ground connection should be used. The power-line end must be grounded to a suitable permanent ground, and the end at the apparatus must be grounded securely through a bolted connection to the apparatus frame.

Included in this instruction is one method for making the conductor splice. Other methods can be used successfully. Most operating companies have their own ideas as to how these joints should be made. One suggestion is added: that the copper splice be made as smooth as possible and as close to the original diameter as practical.

212. Nonsoldered Joints (for Types of Cable Used in Mines).—These instructions apply to those types of all-rubber portable cable that are widely used in coal and other mines on such equipment as gathering reel locomotives, cutters, loaders, and drills. The types covered are single-conductor, two-conductor flat (with the conductors side by side), and two-conductor concentric (with an inner and outer conductor).

This method of jointing eliminates solder, and, although it is thus particularly applicable to work that has to be done in a mine where the explosive hazard is high, it can of course be used for any (600 volts and below) job where the omission of solder seems to be justified or desirable. This type of connector is useful for emergency repairs, because it is simply and easily installed.

213. Nonsoldered Joint for Single-conductor Portable Cable (refer to Fig. 36).—1. Remove the outer jacket and insulation for a distance of approximately 5 in. from each cable end.

2. Overlap the two conductor ends, as shown in the drawing, and install two Newberry clamps at the ends of the conductors.

3. Taper the insulation on each side of the joint, leaving ½ in. of bare conductor between the end of the taper and the edge of the connector.

4. Remove the outer jacket and reinforcing braid to the final dimensions.

5. Thoroughly clean the surface to which splicing gum is to be applied and cover with a coating of rubber cement. Allow the solvent to evaporate.

6. Apply splicing gum to the dimensions as shown in the drawing below.

7. Cover the splicing gum with one layer of friction tape, half-lapped and finally wrapped with reinforcing cord.

8. Taper the ends of the outer rubber jacket and clean the entire surface of the joint.

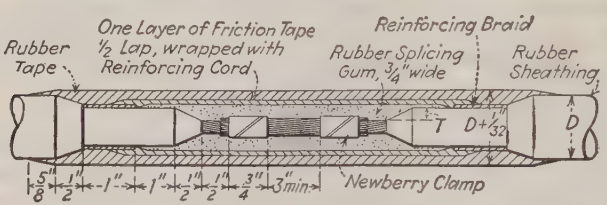


FIG. 36.—Nonsoldered single-conductor cable joint. (*General Electric Co.*)

9. Apply a coating of rubber cement over the entire joint. When the solvent has evaporated, apply the outer jacket with wrappings of splicing gum.

10. Vulcanize the joint.

214. Nonsoldered Joint for Two-conductor (Flat) Portable Cable (refer to Fig. 37).—1. Remove the outer jacket to the dimensions shown in the drawing, making an allowance for approximately a 5-in. overlap of the conductors.

2. When the cable is supplied with jute fillers, these fillers should be laid back over the cable and reassembled later.

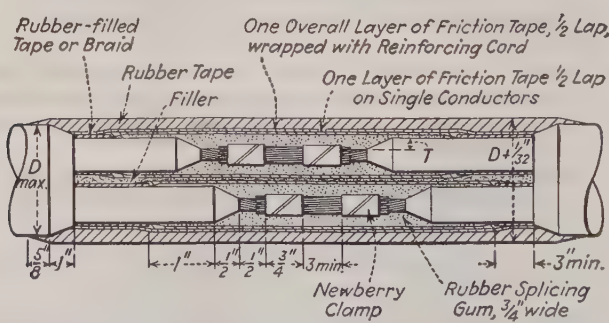


FIG. 37.—Nonsoldered two-conductor (flat) cable joint.

3. Remove sufficient insulation from each of the four cable ends to allow installation of the connectors.

4. The conductors are then connected by overlapping the two ends as shown in the drawing, and a Newberry clamp is installed at each of the

conductor ends. This clamp has been used very successfully around mines for a number of years.

5. Remove the outer tape or braid to the dimensions shown.

6. Taper the conductor insulation on each side of the connectors as shown in the drawings.

7. Thoroughly clean the surface over which splicing gum is applied, and apply a coating of rubber cement. After the solvent has evaporated, wrap splicing gum to a diameter slightly greater than that on the original cable.

8. Cover each insulated conductor with a layer of friction tape half-lapped.

9. If the original cable is supplied with jute or rope fillers, they should be replaced in the interstices of the joint. If rubber fillers were used in the original cable, they should be replaced by rubber fillers (see standard instructions for splicing portable cables in Sec. **211**).

10. After the fillers have been applied, cover the insulated conductors and fillers with a layer of friction tape half-lapped and wrap with reinforcing cord (see the instructions for the splicing of standard portable cables).

11. Taper the ends of the over-all jacket and thoroughly clean the entire surface which is to be covered by rubber tape and apply a coat of rubber cement.

12. After the solvent has evaporated, apply the outer jacket with wrappings of rubber tape to the dimensions that are shown on the drawing.

13. Vulcanize the joint.

215. Nonsoldered Joint for Two-conductor (Concentric) Portable Cable (Refer to Fig. 38).—1. Remove the outer jacket to the distance shown on the drawing, allowing for the overlapping of the conductors. Note that more jacket must be removed from the left-hand end of the joint than from the right-hand end. This is necessary to make room for connecting the outer conductor later.

2. Bend back the outer conductor strands as shown in the drawing. Do not bend the strands to too short a radius, since if the wires become kinked it will be difficult to replace them later.

3. Remove sufficient insulation from each of the inner conductor ends.

4. Overlap the conductors and apply a Newberry clamp at each end. These clamps have been used for years in the mining field with satisfactory results.

5. Taper the insulation on each side of the conductor joint and remove approximately 1 in. of the cable tape or braid, starting at the maximum diameter of the taper.

6. Thoroughly clean the surface over which the splicing gum is to be applied and cover it with a layer of rubber cement.

7. After the solvent has evaporated, apply splicing gum to the dimensions as shown in the drawing below. The diameter of the joint insulation should be slightly greater than the diameter of the original cable.

8. Wrap the insulation just applied with one layer of friction tape half-lapped.

9. The outer conductor should now be placed back over the joint. The strands should be laid back carefully, approaching as near as possible the original lay of the cable strands.

10. The conductor ends are connected together by twisting the several strands together with a pair of pliers. The excess copper is cut off and the ends bent parallel to the axis of the cable. Note that these strands

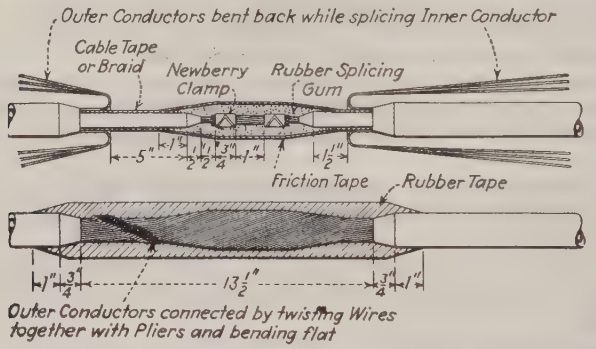


FIG. 38.—Nonsoldered two-conductor (concentric) cable joint. (*General Electric Co.*)

are connected together at the long end of the joint where the diameter is smaller than it is directly over the inner conductor splice.

11. Thoroughly clean the entire surface to be covered with tape, and apply a coat of rubber cement.

12. After the cement solvent has evaporated, apply the outer jacket, using wrappings of splicing tape.

13. Vulcanize the joint.

216. Vulcanizers are easy to operate and can be used very successfully with little experience. These instructions should enable anyone to operate the average steam vulcanizer without any trouble. Steam vulcanizers are generally shipped without water in the jacket. The user should make sure that water is placed in the unit to the proper level before the vulcanizer is used.

Most units are equipped with a relief or safety valve. This valve is set to "pop" at a given pressure. This valve can be adjusted by removing the top and tightening the screw to increase pressure, or loosening the screw to lower the pressure. The pressure control can be set to

open at from 30 to 65 lb. pressure and to close at from 25 to 60 lb. This control can generally be adjusted by tightening or loosening the control-spring tension in the same way as the relief valve is adjusted.

The heaters should always be covered with water to prevent their burning out. If there is no escaping of steam anywhere, a filling of water should last a considerable time, even when used daily. The water should normally be checked about once a week. The vulcanizer should be placed in a practically level position while the current is connected, otherwise the water may drain away from the immersion heaters.

Most steam vulcanizers are operated with electric heating units, but any form of heat can be used, provided it can be carefully controlled so that a constant heat is applied to the joint to be vulcanized. Gas furnaces and blowtorches have been successfully used.

217. General Instructions for Operation of Vulcanizers.—Three factors are essential for the successful vulcanizing of rubber-jacketed cables: time, temperature, and cleanliness.

218. The time required to vulcanize rubber is approximately 15 min.; however, this does not mean that any vulcanizing job can be done in this time. First of all, the mass of rubber, cable, and copper conductors must be brought up to temperature before the cure begins.

The outer rubber that comes in direct contact with the mold begins to cure before the inner mass, but the work must be left in the vulcanizer long enough to cure all the rubber. Therefore, the time will vary considerably, depending on the volume to be heated and the temperature of the work before it is put into the vulcanizer. For instance, in the wintertime a cable brought into the shop or repaired outdoors will require more time than if vulcanized in the hot summertime. Also, a large cable will require more time than a small one. With these factors in mind, it is readily seen that, owing to varying conditions, a definite time schedule cannot be set forth.

It will be found that in most cases the time will be between 30 and 45 min., although there are sometimes conditions that require 1 hr. or even more, and others that require only 20 min.

The exact length of time for curing is not known. In the first place, there is no positive schedule to follow. After a few jobs are done, the time can be estimated. It is best to leave the first few jobs in slightly longer than might seem necessary to be sure of a full cure. Then reduce the time as you gain experience. An approximate schedule for a novice is as follows:

Cable Size, In.	Time, Min.
¾ and smaller	20
¾–1¼	25
1¼–1¾	30
1¾–2¼	35
2¼–3	40
3 –3½	50

This schedule is an estimate for complete splices. When only small patches are made, the time will be somewhat less, as the small volume of rubber and the adjacent old rubber are quickly brought up to temperature, and may be cured before the mass of cable is fully heated.

Care must be taken not to undercure a joint, because undercured rubber deforms easily and therefore makes a poor joint from the abrasion standpoint. A simple method of determining an undercure is to cut in two a piece of the surplus fin, and if the fin will stick together where it was cut, the joint was undercured. Because the fin is thin, it will always cure first. Therefore, the fin might be overcured, but the joint itself might still be undercured.

This indication does not necessarily mean an unsatisfactory job, but is simply mentioned as an aid to the operator.

219. Temperature for Vulcanizing.—The controls on the vulcanizers are set to open at from 30 to 65 lb. steam pressure and close at from 25 to 60 lb. This range under ordinary conditions provides a sufficiently accurate temperature for curing the rubber.

About the only condition that might require any change would be subzero weather during which the vulcanizer itself is exposed. In such cases the radiation is so severe that it may be necessary to increase the pressure by adjusting the control. Since cables are usually repaired indoors, however, extremely cold weather is seldom a factor.

220. Cleanliness in Vulcanizing.—The important reason for vulcanizing electric-cable splices is to make them watertight and give them added strength. Obviously it is necessary for the applied rubber to mold into a solid mass and, furthermore, stick to the old cable jacket.

One of the chief aids in obtaining these results is keeping the work clean. Oil or grease is known to be detrimental to rubber, and dust or dirt on the surface of the rubber being applied is likely to prevent its molding together. When new rubber is applied to the old cable jacket, it must be absolutely clean to obtain adhesion.

221. How to Patch a Jacket.—The amount of work to be done depends on the extent of the injury. For instance, a small cut can in many cases be patched simply, whereas a severe injury may require the removal of the portion of jacket that is injured and replacing this portion with new rubber. In any case, thoroughly inspect the conductor insulation at the injury to be sure it is not also injured. If it is, the jacket should be removed for a sufficient length to repair properly the conductor insulation. It may be necessary to make a complete splice.

To vulcanize new rubber to old rubber, it is necessary to roughen the old rubber and scrape or grind off any old scale or coating at the place where the new rubber is expected to stick. The old rubber should also be prepared for 1 in. around the injured spot.

When the jacket must be removed, it will be found easier to clean and roughen the cable for about 2 in. each way beyond the portion to be removed before cutting it out.

There are two kinds of rubber used in the repair of electric cables: jacket rubber and insulating rubber.

The insulating rubber is used only for conductor insulation. The jacket rubber is used for all outside work.

When new rubber is applied to the old, proceed as follows:

1. Clean and roughen old rubber as described previously.

2. With naphtha or benzol, thoroughly clean the areas where the rubber is to be applied and allow them to dry.

3. Brush rubber cement over the surfaces to which the new rubber is expected to stick, as well as an inch or so beyond. Allow the solvent to evaporate.

4. Apply new rubber, which is supplied in tape form. If the rubber is wrapped tightly and evenly, all air is excluded, and the new rubber does not have to be built up much larger than the mold. Only a little experience is necessary to demonstrate how much rubber to apply.

5. The repair is now ready to vulcanize. Naturally a suitable mold must be on hand. Molds are made in several types and sizes to fit the particular joint in question.

The proper mold should be hot when ready to use. Swab or brush sparingly an application of mold dressing in the mold before putting in the job.

Shut mold to within $\frac{1}{16}$ in. of being closed, depending on size of cable, and allow to set for about 5 min. to permit the rubber to soften, then close mold. When this procedure is followed, there is a better chance of filling out low places due to unevenness in wrapping. Furthermore, when a complete splice is made, there may be a distortion of core assembly if full pressure is applied before the rubber is allowed to soften.

6. After curing, remove from mold, cut off surplus fins, apply wax, and the job is finished. The joint should be allowed to cool somewhat before it is removed from the mold.

222. Temporary Vulcanizing Equipment.—Frequently it is necessary to vulcanize a cable joint in the field, and no equipment is available. To take care of this condition, temporary vulcanizing equipment can be constructed.

An open-top vat of suitable size should be obtained. This vat should be large enough to allow the entire joint to be submerged in the heated liquid of the vat when the spliced cable is placed directly over the vat, allowing the cable joint to dip into the vat.

Paraffin is generally used in the vat for the vulcanizing medium, but any wax with a high enough boiling point could be used. In no case should oil be used.

After the joint has been constructed in the usual manner, it should be placed in a suitable mold. There are a number of different molds that can be easily constructed.

1. Split a piece of pipe which has approximately the same inside diameter as the completed splice. The two pieces of pipe should be held

tightly on the joint by wrappings of wire or metal tape or standard "U" clamps.

2. In a metal block, drill a hole approximately the same diameter as the splice. Split the block in half, and place it over the joint. The two halves of the block should be held tightly together by means of bolts or acceptable clamps.

If it is possible, the molds should be heated up to about 275°F. before they are placed over the joint. The inside of molds should also be coated with an approved mold dressing to obtain the best and most workmanlike finished splice.

223. The procedure to follow in vulcanizing a joint with the equipment of Sec. 222 is as follows:

1. Make up the joint in the usual manner.

2. Preheat the molds if possible up to 275°F., coat them with a mold dressing, and clamp them over the joint.

3. In the meantime, the paraffin in the vat should be heated and held to from 275 to 300°F. by satisfactory heating equipment. Blowtorches or gas furnaces can be used for this purpose, or any available heating equipment which will hold these temperatures satisfactorily.

4. Place the joint in the heated paraffin, bearing in mind that the entire joint and mold are submerged in the liquid.

5. Hold the joint in this medium for a period of time depending on the size of joint involved and the thickness of rubber to be vulcanized, holding the temperature of the paraffin as nearly constant as possible. The approximate time required to vulcanize the joint is listed in the steam-vulcanizer instructions. The exact time for curing a splice can best be obtained by experience with the particular equipment used.

6. When the splice is cured, it should be removed from the vat and allowed to cool for a time before removing the mold.

It is natural that perfect results cannot be obtained with this temporary equipment, but a number of splices have been vulcanized by this method and all have operated satisfactorily when properly made.

The mold dressing generally used is a saturated solution of soap chips.

224. Terminal connections of conductors should be made by means of solder lugs or solderless connectors, except that No. 8 or smaller conductors may be connected to binding posts by means of clamps or screws, provided the terminal plates of the binding parts have upturned lugs. The upturned plates are necessary so that the wires will not be forced out of place as the screw or nut is tightened.

225. The correct method of "making-up" a lead wire around a binding post is shown in Fig. 39. First, an eye, of such internal diameter that it will slip over the post, is bent with the pliers in the bared-and-cleaned end of the lead wire, as illustrated at I. Then the eye is dropped down over the post (III) in such a position that rotation of the bolt or nut in tightening will tend to wrap the eye end around the post rather than to

unwrap it. That is, the eye should wrap around the post in a right-handed direction, in the same direction as that in which the nut rotates while being turned on. If the eye is laid on left-handed as at II, it will unwrap and open while the nut is being turned tightly down on it.

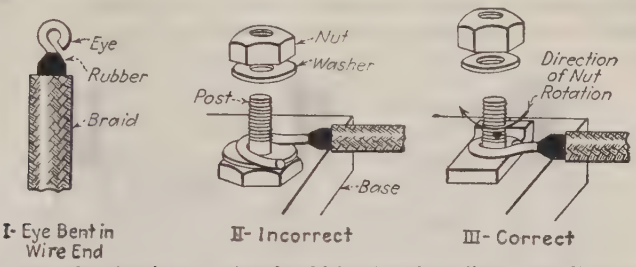


FIG. 39.—Showing how a wire should be "made-up" on a binding post.

226. When soldering wires in terminal lugs, if many lugs are to be soldered, a convenient and time-saving method of making the connections is to melt a pot of solder over a plumbers' furnace, heat the lug in the solder, pour the solder in the hole in the lug and then plunge the bared end of the conductor into it, as shown in Fig. 40. The insides of the holes of many commercial lugs are "tinned" so the solder adheres to them readily. The bared end of the conductor should also first be tinned. This may be done as follows: The end of the wire is carefully scraped with a knife or with a piece of fine sandpaper (the sandpaper is best because it cannot nick the wire) and then smeared with soldering flux and thrust into the solder pot. If a soldering stick is used, the wire must be heated in the solder before the stick compound will melt and adhere. It requires but a short time to tin the wire end in the pot.

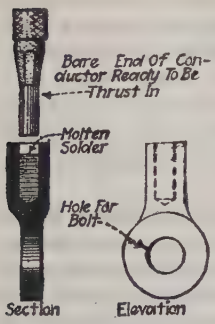


FIG. 40.—Soldering wire in lug.

NOTE.—Immediately after the tinned end is pushed into the hole in the lug, the lug should be soused with a piece of wet waste to cool it rapidly. Scrape or file off any shreds or globules of solder that adhere to the exposed surfaces of the lug and brighten it with fine sandpaper if necessary.

227. In "skinning" a wire end which is to be soldered into a lug, the insulation should be cut back just far enough so that it will abut against the shoulder of the lug, as suggested in Fig. 41, I. The appearance is very unsightly and indicates careless work if there is a gap between the shoulder and the insulation, as at II. If, because of some mishap there results a connection which has the appearance of II, a partial correction can be made by filling the gap with servings of tape, as shown at III.

The tape of the standard ¾-in. width should be torn into strips about ¼ in. wide before applying.

228. Only enough molten solder should be poured into the hole in the lug to fill it almost to the brim when the conductor is in position. If too much is poured in, it will be squeezed out by the wire and will flow over the lug. It must then be removed at a sacrifice of time.

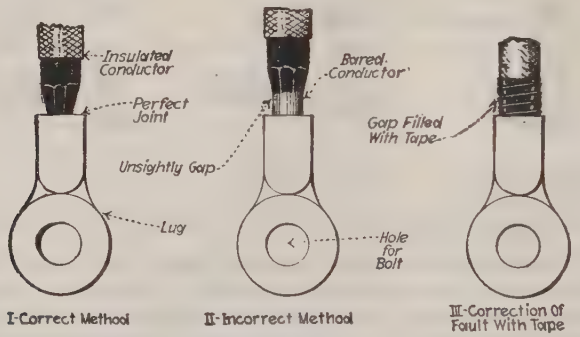


FIG. 41.—Finished connections.

229. To insure proper adhesion between wire, solder, and lug the temperature of all three must be above the melting point of solder when they are brought together in soldering. If this condition is not fulfilled, only a good friction fit of all three parts will result. Such a friction fit does not afford a good electrical connection. To secure maximum mechanical strength and electrical conductivity, it is absolutely essential that the solder be maintained at the melting point until it has thoroughly permeated the interstices of the conductor.

230. The wire terminal and lug should be held in the molten solder until they acquire the temperature of the solder. To prevent adhesion of solder to the outside of the lug a light oil or possibly soft soap should be applied to its outer surfaces. Be careful to see that no oil is permitted to reach the inside of the lug. It will be found advisable, when holding the bared ends of heavy conductors in the solder pot, to wrap the insulation with a rag previously wrung out in cold water to prevent, insofar as is possible, the melting of the insulating compound and the consequent smearing of the terminal. Any such smearing will not impair the effectiveness of the joint if it is properly made, though it will detract from the appearance of the finished job.

231. Another method of soldering wires in lugs is to heat the lug with a blowtorch flame. When the lug is sufficiently hot, wire solder is fed into the hole. The solder melts and the bared conductor end is then thrust into it, as above described. However, the use of a blowtorch in this way should be avoided if possible, as it blackens the exposed surfaces

of the lug. A cleaning with fine sandpaper is then necessary, and it requires considerable time.

232. Some suggestions for handling blowtorches are: Only the very best grade of gasoline should be used, and it must be clean and kept in a clean can, otherwise the burner will become clogged. Never try to fill a torch from a big can. A pint or quart receptacle should be used for this purpose. If this is done, the torch can be held in one hand and filled with the other without danger of overfilling or spilling. The torch should be a little more than two-thirds full, so that there will be room for sufficient air to prevent the necessity of frequent repumping to maintain the pressure. See that the filler plug is closed tight, to prevent the escape of air from tank. The fiber washer under the plug must be replaced when worn out. Common washing soap rubbed into thread and joints will stop leaks. The pump should be in good working order; a few drops of lubricating oil well rubbed in will soften the pump washer. Do not turn the needle valve too tight, as there is danger of enlarging the orifice of the burner. See that the burner is sufficiently heated when starting. One filling of the drip cup is generally sufficient if the flame is shielded from draft while heating the burner; if it is not, fill the cup again and light the gasoline as before. A long or yellow flame or raw gasoline shooting from the burner shows that the burner is not hot enough to properly generate gas. When a gasoline torch is used, as much as 90 per cent of its heat may be dissipated, without doing any work whatever. When performing most blowtorch operations, a great part of this heat may be readily saved by making a shield of sheet iron or asbestos to direct the heat to the object to be heated.

233. Use of Solderless Connectors.—The use of solderless devices to provide the required mechanical and electrical connections between conductors is often advisable in place of the jointing methods previously described. Likewise, the fastening of lugs to cable ends may be accomplished by solderless connectors in place of the molten-solder method.

A wide variety of mechanical solderless connectors are used for practically all conditions where mechanical and electrical connections between two conductors are necessary. Many purchased pieces of equipment are being equipped with solderless terminal devices. Some are of the type, particularly in the smaller sizes, where the solderless connector forms an integral part of the equipment. Other pieces of equipment employ solderless connectors that are removable in a manner comparable to the ordinary solder lug.

Solderless connectors permit rapid connection to conductors and eliminate the human element in the making of satisfactory soldered contacts. They are, however, somewhat more expensive than conventional devices used where solder is employed.

When employing solderless connectors, it is very essential to select devices which meet the following fundamental requirements:

1. Ample contact area between wire and device.
2. High contact pressure.
3. Ability to maintain high contact pressure permanently.

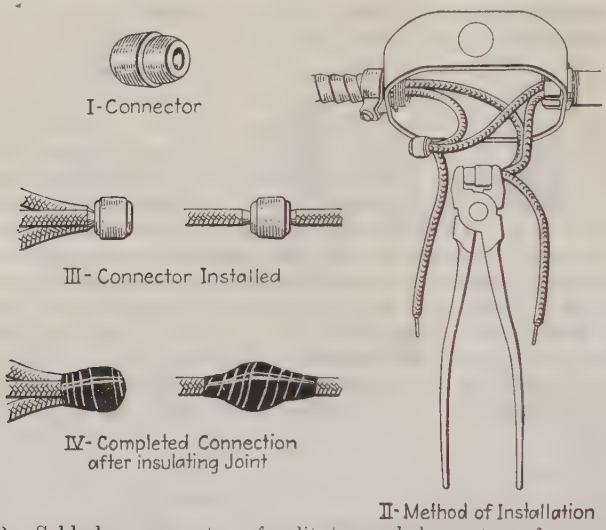


FIG. 42.—Solderless connector of split tapered-sleeve type for connecting small wires. (*Thomas & Betts Co.*)

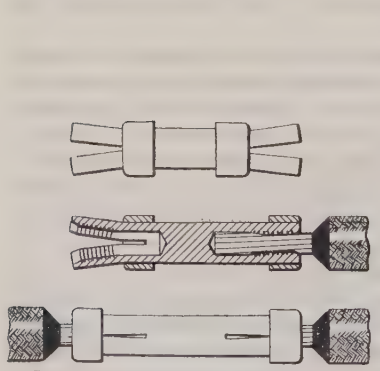


FIG. 43.—Solderless connector of split sleeve type for making straight joint in small wires. (*Thomas & Betts Co.*)

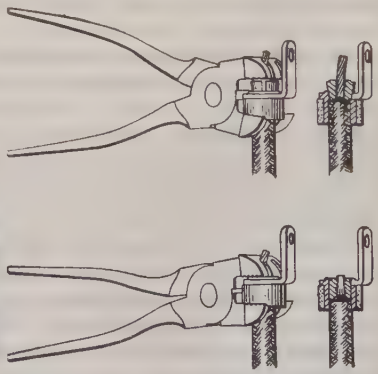


FIG. 44.—Solderless lugs of split tapered sleeve type for small wires. (*Thomas & Betts Co.*)

A joint or tap connection made with a solderless device may be insulated in the same general manner as a soldered joint, or special insulating covers may be employed.

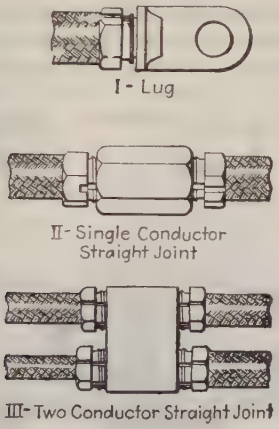


FIG. 45.—Solderless connectors and lug of split tapered-sleeve type for small wires. (*National Electric Products Corp.*)

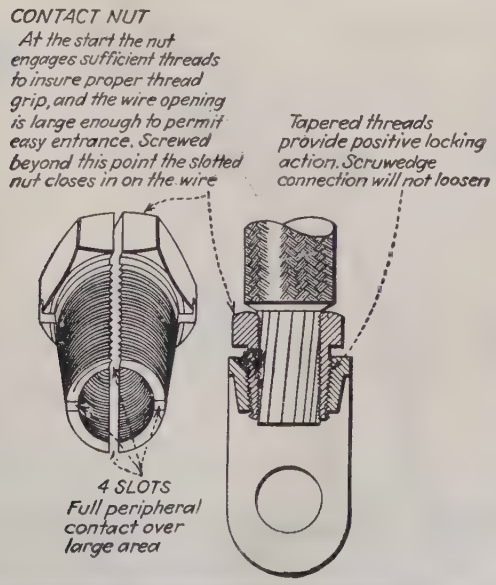


FIG. 46.—Principle of split-tapered-sleeve solderless lug. (*National Electric Products Corp.*)

234. Many different types of solderless devices are available to meet the requirements for making almost any type of joint, tap, or terminal connection. The two most common types are (1) the pressure washer

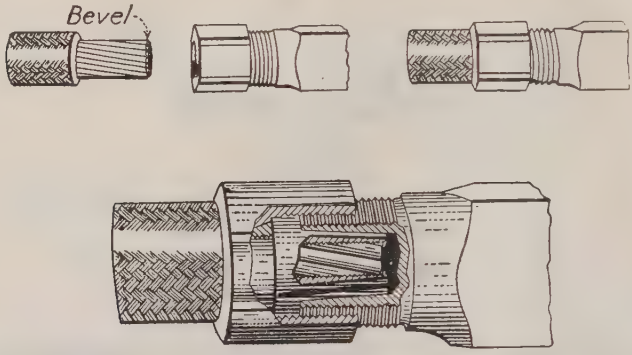


FIG. 47.—Assembling split-tapered-sleeve lug. (*National Electric Products Corp.*)

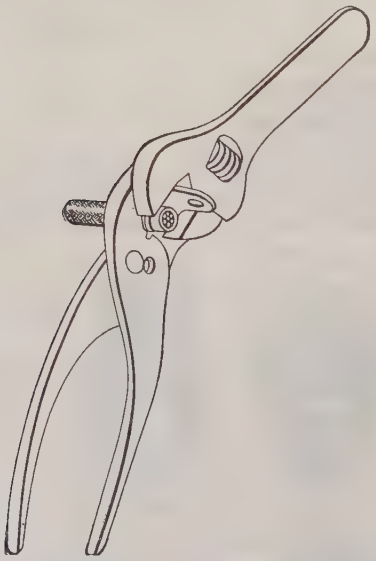


FIG. 48.—Tightening split-tapered-sleeve lug. (*National Electric Products Corp.*)

and nut type, and (2) the type employing a split tapered sleeve. Several types of solderless connectors, taps, and lugs are illustrated in Figs. 42 to 52.

235. Splices in bare copper aerial conductors may be made by means of a soldered splice as shown in Fig. 53, by means of a solderless splicing sleeve as shown in Fig. 54, or by means of a rolled or drawn copper connector as shown in Figs. 55 and 57. A soldered splice should be mechanically and electrically secure before solder is applied. There should be

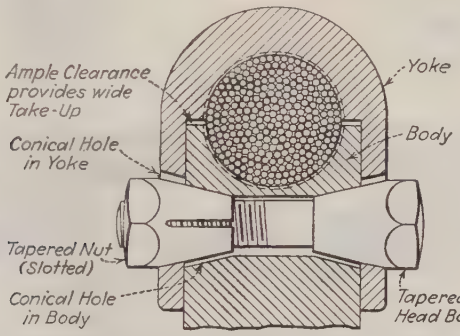


FIG. 49.—Pressure-washer-and-nut type of solderless connector. (*National Electric Products Corp.*)

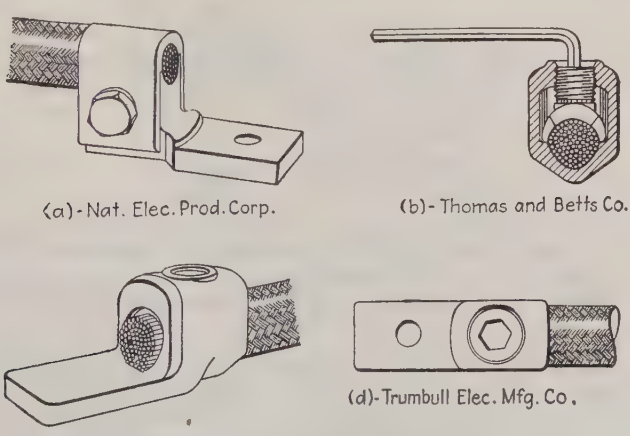


FIG. 50.—Solderless lugs of pressure-washer-and-nut type.

at least five turns in the neck of a splice to ensure that the unsoldered splice will be as strong as the wire of which it is made. All splices in wires which carry electricity should be soldered in the neck. It is not always necessary to solder the end turns.

Joints made with seamless solderless splicing sleeves (Fig. 54) are generally considered to be more reliable than soldered joints. The

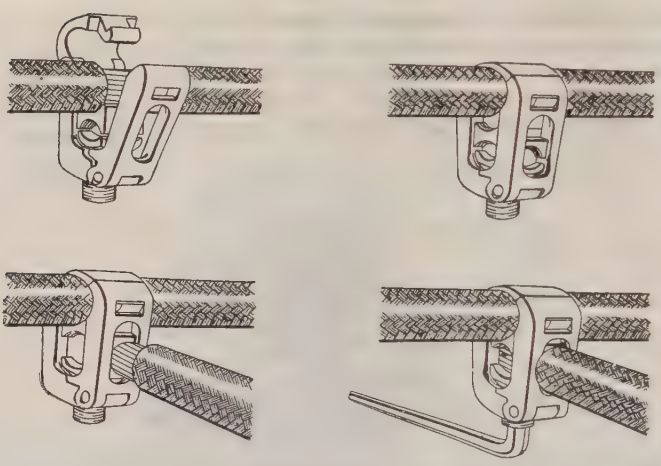


FIG. 51.—Solderless lug connector of pressure-washer-and-nut type. (*Thomas & Betts Co.*)

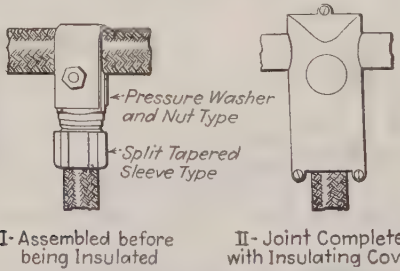


FIG. 52.—Solderless tap connector of combined split-tapered-sleeve-and pressure-washer-and-nut type. (*National Electric Products Corp.*)

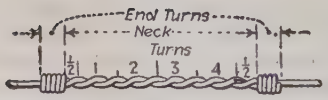


FIG. 53.—Bare-copper-line-wire splice.

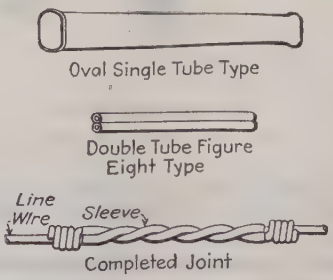


FIG. 54.—Splice made with McIntire sleeve.

sleeves are made of high-conductivity copper and may be of the double tube figure-eight type or of the oval single-tube type. These sleeves are sometimes called McIntire sleeves. In making a splice, the sleeve should be twisted with long-handled tongs for $3\frac{1}{2}$ or 4 turns in a direction so that the helix of the twisted sleeve will be in the opposite direction to the lay of the strand.

A splice of the highest grade is undoubtedly made with a rolled or drawn seamless connector. The drawn connector will produce a splice of the lowest resistance and highest tensile strength. The rolled seamless

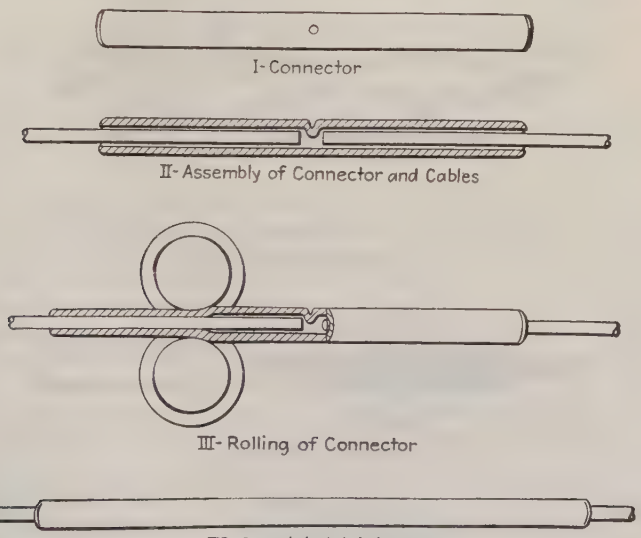


FIG. 55.—Rolled seamless connector for bare copper wire. (*Anaconda Wire and Cable Co.*)

connector consists of a piece of seamless copper tubing with an inside lacquered surface. Embedded in the lacquer are hard carbon particles that lock both ways on the conductor and in the connector as the connector is rolled on the wire. The connector is rolled on with a simple tool, which exerts heavy pressure, fitting the wire so tightly that internal corrosion is prevented, and therefore the ohmic resistance of the splice remains constant. Rolling the connector works the metal so that it is hardened and lengthened to give a long, sure grip on the wire.

Figure 55 illustrates the connector, assembly of joint, method of rolling, and finished joint. The rolling tool employed is shown in Fig. 56.

Drawn seamless connectors consist of a short piece of seamless copper tubing with its center reduced for a short distance to a diameter slightly

less than that of the die to be used in making the splice. The conductors to be joined are inserted the full length of the opening in each end of the connector. The connector is made large enough to fit easily over the conductor ends. The connector is compressed radially over the conductor by means of a split die started at the reduced portion of the con-

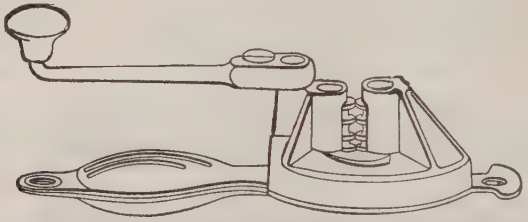


FIG. 56.—Rolling tool for applying rolled seamless connectors. (*Anaconda Wire and Cable Co.*)

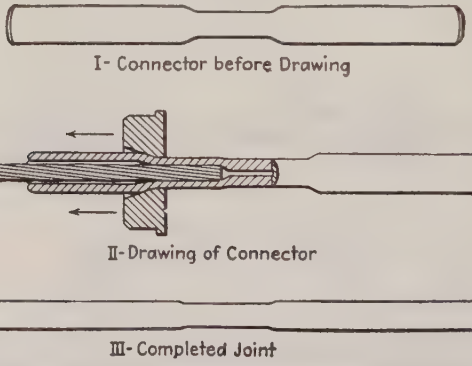


FIG. 57.—Drawn seamless copper connector for bare copper wire. (*Anaconda Wire and Cable Co.*)

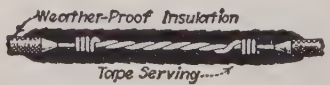


FIG. 58.—Western Union splice insulated with tape.

nector and drawn over each end in turn. Figure 57 illustrates the connector, assembly of joint, method of drawing, and finished joint.

236. Splices in covered aerial conductors are made in the same manner as for bare aerial conductors of the same material. The splice may be covered simply with friction tape as shown in Fig. 58, but it is preferable to apply rubber tape covered with two layers of friction tape as shown in (Fig. 59).

237. Splices in steel, or copper and steel, stranded cables are generally made with seamless solderless splicing sleeves in the same manner as described in Sec. **235** for bare copper wires. Steel sleeves are used for all-steel wires, and either copper or steel sleeves for the combination cables.

238. Splices in copperweld, or copperweld and copper, cables are made in the same manner as for bare copper wires discussed in Sec. **235.** Two sleeves should be used for making each splice in extra-high-strength cable.

FIG. 59.—Splice in covered conductor.

239. Splices in all-aluminum cable, or aluminum cable, steel-reinforced, are made by means of twisted solderless oval sleeves or solderless compression sleeves. The former joints are made with oval single-tube sleeves of seamless aluminum similar to the copper sleeves used for splicing copper wires as shown in Fig. 54. For all-aluminum cables, one sleeve is sufficient for each joint. For aluminum cable, steel reinforced, two sleeves should be used for each joint, except for Nos. 8 and 7 cables, where one sleeve is sufficient. Two twisting wrenches (Fig. 60) are employed for twisting the sleeve and cable into the finished joint. The wrenches should be rotated in a clockwise direction when facing the

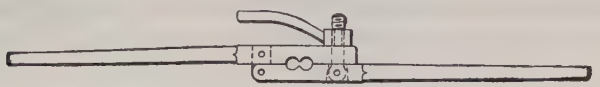


FIG. 60.—Twisting wrench for applying aluminum twisting sleeves. (*Aluminum Co. of America.*)

mouth of the sleeve. Before making the joint be sure that the inside of the sleeves and the ends of the cable are perfectly clean and free from dirt and grease. The following methods of making the joints are recommended by the Aluminum Co. of America.

1. For aluminum cable, steel-reinforced (ACSR), sizes 4/0 to 1/0, give each sleeve 4½ complete twists distributed as shown in Fig. 61. This requires setting one wrench at the inner end of each sleeve and setting the other wrench three times progressing toward the outer end of each sleeve. Make these in the order shown in the illustration. At the ends of the joint the wrench should not be less than ¼ in. from the end of the sleeve.

2. For aluminum cable, steel-reinforced (ACSR), sizes 1 to 6, give each sleeve four complete uniform twists as shown in Fig. 62. This requires one setting of the twisting wrenches at the ends of each sleeve. The wrenches should not be less than $\frac{1}{4}$ in. from the end of the sleeve.

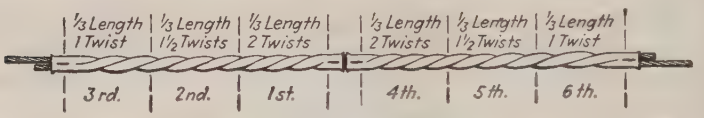


Fig. 61.—Joint for ACSR cable sizes 4/0 to 1/0. (*Aluminum Co. of America.*)

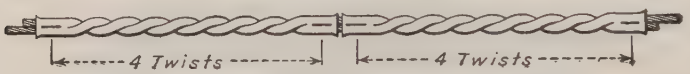


Fig. 62.—Joint for ACSR cable sizes 1 to 6. (*Aluminum Co. of America.*)

3. For twisting joints consisting of a single sleeve, as used on all-aluminum cables and sizes 7 and 8 ACSR, give the middle third as many complete twists as it will stand (from 2 to $3\frac{1}{2}$ depending upon the size of cable and length of sleeve). Then give each end third length one complete twist.

240. Compression joints on all-aluminum cable are made by compressing a seamless aluminum sleeve (Fig. 63) over the butted ends of the two cable lengths. A portable hydraulic compressor and dies are required for making these joints. The following method of making a joint is recommended by the Aluminum Co. of America.

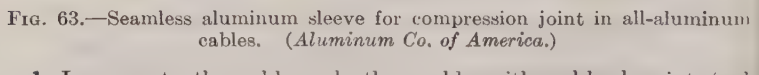


Fig. 63.—Seamless aluminum sleeve for compression joint in all-aluminum cables. (*Aluminum Co. of America.*)

1. Impregnate the cable ends thoroughly with red-lead paint (red lead and linseed oil) by dipping them in a bucket of paint a little deeper than one-half the length of the joint.

2. Slip the cable ends into the joint, taking care that they meet exactly at the middle.

3. Compress the joint, starting at the center and working toward the ends, allowing dies always to overlap previous position.

For old or blackened cable, each strand should be scraped or sandpapered clean. The bore of the joint is large enough to make it easy to insert the end of the cable after the strands have been opened up, cleaned, and rearranged.

In making a repair joint between a piece of new cable and a piece of old cable, the most convenient method is first to run the end of the old cable clear through the joint, then open up and clean the end of each

strand for a distance equal to one-half the length of the joint. Replace the strands, impregnate with red-lead paint, and pull the cable back until the end is exactly in the middle of the joint. Then insert the new cable at the outer end of the joint after first removing grease from the strands and impregnating with red-lead paint.

241. Compression joints for most aluminum cable, steel-reinforced, consist as illustrated in Fig. 64 of a steel compression sleeve (item 1) on the steel core, and an aluminum compression sleeve (item 2) on the complete cable. The over-all compression sleeve is fitted with two holes through which a heavy red-lead filler is injected. The holes are sealed

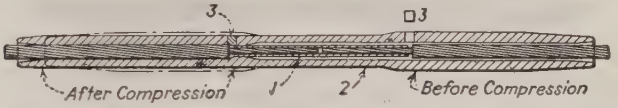


FIG. 64.—Compression joint for ACSR cable. (*Aluminum Co. of America.*)

with aluminum plugs (item 3). The following method of making a joint is recommended by the Aluminum Co. of America.

1. Before applying the joint see that its bore and the ends of cable to be jointed are free from grease and dirt, *i.e.*, thoroughly clean.

2. Slip the aluminum compression joint over one cable end and back out of the way along the cable.

3. Using a hack saw, cut off the aluminum strands, exposing the steel core for a distance of a little more than half the length of the steel compression joint Use care not to nick the steel core with the saw. Before doing this serve the cable with wire just back of the cut.

4. Insert the steel core into the steel compression joint, bringing the ends exactly to the center.

5. Compress the steel compression joint, beginning at the center and working out toward the ends, allowing dies always to overlap previous position.

6. Remove serving from the cable and slip the aluminum compression joint up over the steel compression joint. Center the aluminum joint by sighting the ends of the steel joint through the filler holes in the aluminum joint.

7. Using a calking gun (¼-in. round nozzle, maximum), inject heavy red lead (approximately 93 per cent red lead, 7 per cent linseed oil by weight) through both holes provided in the aluminum joint until the space between the aluminum joint and the steel joint is completely filled. This can be observed through the filling holes.

8. Insert the aluminum plugs in the filler holes and hammer them firmly in place. They will be completely locked during compression.

9. Compress the aluminum compression joint, starting at the center and working toward the ends, allowing dies always to overlap previous position.

Some types of aluminum cable, steel-reinforced, have such a large percentage of steel that the steel compression sleeve of the above joint has a larger diameter than the complete cable. This necessitates the use of the joint shown in Fig. 65. One end of the over-all aluminum sleeve is counterbored so that this end of the aluminum sleeve can be slipped over the steel sleeve. The space between the counterbore and the cable is filled with a third aluminum sleeve (item 4). The procedure in making such a joint is in general the same as previously described. It is self-

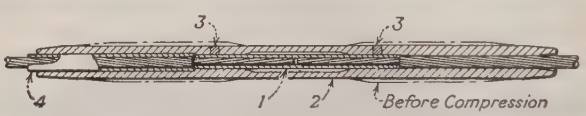


FIG. 65.—Compression joint for ACSR cable with large steel core. (*Aluminum Co. of America.*)

evident, however, that the aluminum joint (item 2) must be slipped over the cable with that end which has the smaller bore first. Also the sleeve (item 3) must be slipped on the other end of the cable; both before the steel joint (item 1) is applied. After the steel joint is applied and before the aluminum joint is slipped into place, the sleeve is slipped along until flush with the ends of the aluminum strands. Otherwise the procedure is the same as previously described for making compression joints in aluminum cable steel-reinforced.

DIVISION 3

CIRCUITS AND CIRCUIT CALCULATIONS

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TYPES OF CIRCUIT

1. A series circuit is one in which all components are connected in tandem as in Figs. 1 and 2. The current at every point of a series circuit

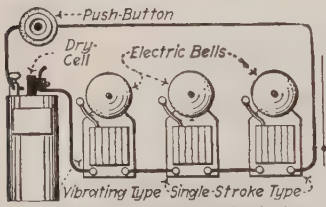


FIG. 1.—Series electric-bell circuit.

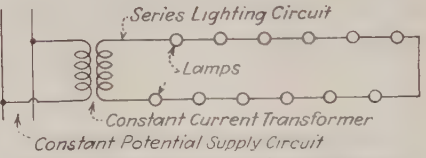


FIG. 2.—Series street-lighting circuit.

is the same. Series circuits find their most important commercial application in series street lighting. They are seldom if ever used in this country for the transmission of power.

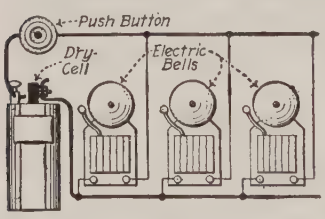


FIG. 3.—Electric bells in parallel.

2. Multiple, parallel, or shunt circuits are those in which the components are so arranged that the current divides between them (Figs. 3 and 4). Commercially, the distinction between multiple and series circuits is that in series lighting circuits the current is maintained constant and the generated e.m.f. varies with the load, whereas with multiple circuits the current through the generator varies with the load and the generator e.m.f. is maintained practically constant.

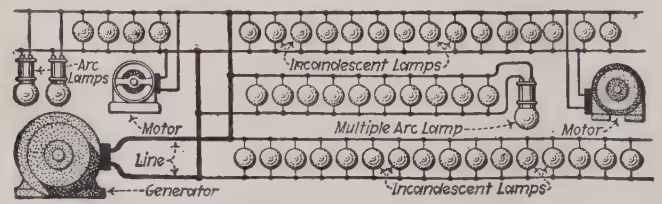


FIG. 4.—A multiple circuit for light and power.

3. Adding receivers in parallel on multiple circuits is really equivalent to increasing the cross section of the imaginary conductor formed by all the receivers in parallel between the + and the − sides of the circuit.

4. The distribution of current in a multiple circuit is shown in Fig. 5. Motors, heating devices, or other equipment requiring electricity for their

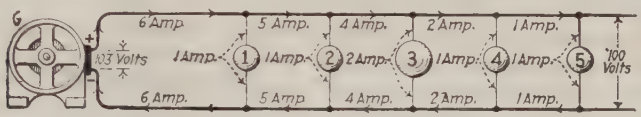


FIG. 5.—Multiple-circuit currents.

operation could be substituted for the incandescent lamps if the proper current values were substituted for those shown. Note that the current in the main conductors decreases toward the end of the run and that the current supplied by the source—the generator—is equal to the sum of the currents required by all the components. The voltage at the end of the run is less than that at the generator.

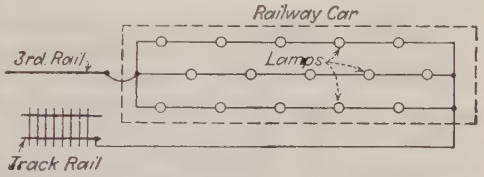


FIG. 6.—Multiple-series circuit supplying lamps on a railway car.

5. A multiple-series or parallel-series circuit consists of a number of minor circuits in series with each other and with several of these series circuits then connected in parallel, as shown in Figs. 6 and 7.

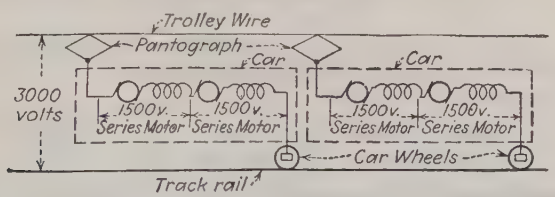


FIG. 7.—Multiple-series circuit supplying motors on railway cars.

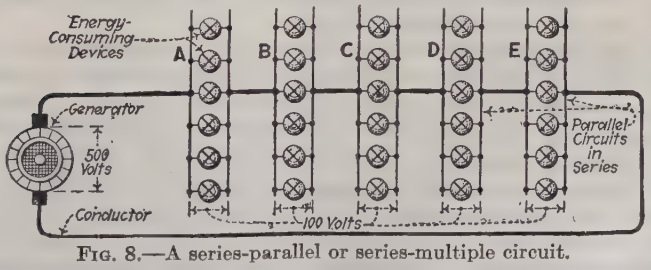


FIG. 8.—A series-parallel or series-multiple circuit.

Incandescent lamps and motors used in railway work are sometimes arranged in this way. For example, on a railway car operating from a 600-volt third rail, the 120-volt lamps are connected 5 in series (see Fig. 6).

The motors on railway cars which operate from a 3,000-volt d-c, overhead trolley wire are usually connected 2 in series so that the voltage per motor will be only 1,500 volts (see Fig. 7).

6. A series-multiple or series-parallel circuit is one wherein a number of minor circuits are first connected in parallel, and then several of the parallel-connected minor circuits are connected in series across a source of e.m.f. as in Fig. 8. This method of connection is seldom used. (There appears to be a difference of opinion as to what constitutes a series-multiple and what a multiple-series circuit. The definitions of Secs. **5** and **6** are in accordance with the practice of the General Electric and Westinghouse companies.)

7. A divided circuit (Fig. 9) is really one form of a multiple or parallel circuit. The distinction between the two sorts appears to be that, as ordinarily used, the term "divided" refers to an isolated group of a few conductors in parallel rather than to a group of a large number of conductors in parallel.

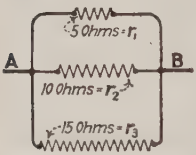


FIG. 9.—A divided circuit.

8. The joint resistance of a number of conductors in parallel can be computed with the following formula. There should be as many terms in the denominator of the formula as there are conductors in parallel.

$$R = \frac{1}{\frac{1}{r_1} + \frac{1}{r_2} + \frac{1}{r_3} + \frac{1}{r_4}, \text{ etc.}} \qquad (1)$$

Example.—What is the joint resistance of the conductors in the divided circuit shown in Fig. 9? In other words, what is the resistance from A to B?

Solution.—Substitute in the formula

$$R = \frac{1}{\frac{1}{r_1} + \frac{1}{r_2} + \frac{1}{r_3}} = \frac{1}{\frac{1}{5} + \frac{1}{10} + \frac{1}{15}} = \frac{1}{\frac{6}{30} + \frac{3}{30} + \frac{2}{30}} = \frac{1}{\frac{11}{30}} = 1 \times \frac{30}{11} = 2.73 \text{ ohms}$$

9. Multiple circuits are employed for the distribution of electrical energy for all lighting and power work with the exception of street lighting, where series circuits frequently are used.

10. The complete electric system from the generating plant to the particular piece of equipment utilizing the electrical energy for heating, lighting, power, etc., may be divided into three main parts. These are the transmission system, the distribution system, and the interior wiring in the building where the energy is utilized. Two simple complete electric systems illustrating the component parts are shown in Figs. 10 and 11. All wires of a circuit are represented for simplicity by a single line. Voltages commonly used for the different parts of the system are indicated on the figures. In the system shown in Fig. 10 the electricity is generated as alternating current at 2,300 volts. At the generating station it is stepped up to 44,000 volts and transmitted at this voltage over the transmission system to the substation. In the substation the energy

is converted by means of a rotary converter to direct current. From the substation the energy is distributed over two distribution systems to the different buildings. One of these distribution systems is two-wire, 230-

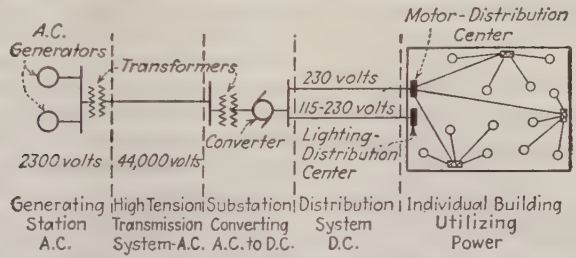


FIG. 10.—Simple complete electric system, generating and transmitting alternating current, distributing direct current.

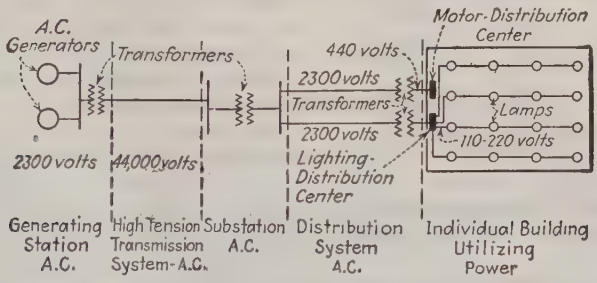


FIG. 11.—Simple complete electric system, generating, transmitting, and distributing alternating current.

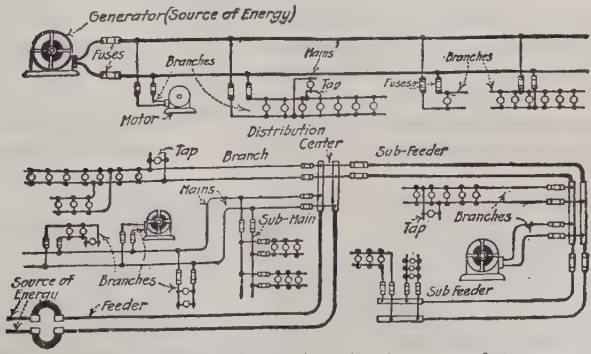


FIG. 12.—Diagram illustrating circuit nomenclature.

volt direct current for the motor load, and the other is three-wire, 115- to 230-volt direct current supplying the energy for lighting. In the system of Fig. 11 the energy is generated, transmitted, and distributed as alternating current throughout.

11. A feeder (or feeder circuit) (Figs. 12 to 14) is a set of conductors in a distributing system extending from the original source of energy in the installation to a distributing center and having no other circuits connected to it between the source and the center. The source may be a generating station or a substation or, in the case of building or house wiring, a connection to the service conductors from the street (see Figs. 12, 13 and 14).

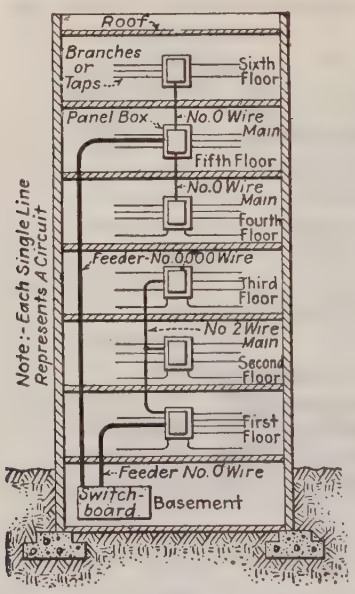


FIG. 13.—Examples of feeders, mains, and branches.

12. A subfeeder is an extension, fed through a cutout, of a feeder or of another subfeeder, from one distributing center to another and having no other circuit connected to it between the two distributing centers. A subfeeder is a sort of tie line (see Figs. 12 to 14).

13. A main (Figs. 12 to 14) is any supply circuit to which other energy-consuming circuits (submains, branches, or services) are connected through automatic cutouts (fuses or circuit breakers) at different points along its length and which is of the same size wire for its entire length and which has no cutouts in series with it for its entire length. Where a main is supplied by a feeder, the main is frequently of smaller wire than the feeder which serves it. An energy-utilizing device is never connected directly to a main, a cutout always being interposed between the device and the main.

14. A submain (Fig. 12) is a subsidiary main, fed through a cutout from a main or from another submain, to which branch circuits or services are connected through cutouts. A submain is usually of smaller wire than the main or other submain which serves it.

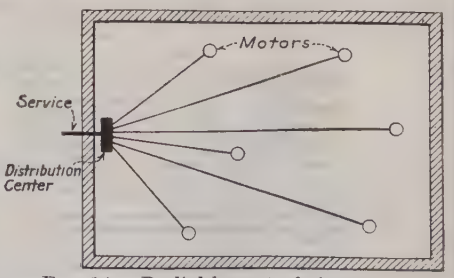


FIG. 14.—Radial layout of circuits.

15. A branch or branch circuit (Fig. 12) is a set of conductors feeding, through an automatic cutout (from a distribution center, main, or sub-

main) to which one or more energy-consuming devices are connected directly, *i.e.*, without the interposition of additional cutouts. The only cutout associated with a branch is the one through which the branch is fed at the main, submain, or distribution center.

16. A tap or tap circuit (Fig. 12) is a circuit which serves a single energy-utilizing device and is connected directly to a branch without the interposition of a cutout.

17. A distributing or distribution center in an electrical-energy distribution system is the location at which a feeder, subfeeder, or main connects to a number of subordinate circuits which it serves. The switches and automatic cutouts for the control and protection of the subcircuits are, usually, grouped at the distributing center. In interior-wiring parlance, a distributing center is often an arrangement or group of fittings whereby two or more minor circuits are connected at a common location to another larger circuit. A panel box or a group of porcelain cutouts is a distributing center (see Fig. 12).

18. A service is the conductors and equipment for delivering electric energy from the secondary distribution or street main, or from a distribution feeder or from the transformer, to the wiring system of the premises served.

A service cable is the service conductors made up in the form of cable.

Service conductors are that portion of the supply conductors which extends from the street main or duct or from transformers to the service equipment of the premises supplied. For overhead conductors this includes the conductors from the last line pole to the service equipment.

A service drop is that portion of overhead service conductors between the pole and the first point of attachment to the building.

Service-entrance conductors are that portion of service conductors between the terminals of service equipment and a point outside the building, clear of building walls, where they are joined by tap or splice to the service drop or to street mains or other source of supply.

Where service equipment is located outside the building walls, there may be no service-entrance conductors, or they may be entirely outside the building.

ARRANGEMENT OF CIRCUITS

19. Arrangement of Circuits.—In each of the three component parts of the electric system (see Sec. **10**) the circuits may be arranged in one of various ways and in some cases in a combination of two or more ways. These different arrangements may be classified as follows:

1. Radial.
2. Radial group.
3. Tree.
4. Combination of radial group and tree.
5. Ring or loop.
6. Network.

20. In a radial layout of the circuits, an individual circuit is run from the source of supply for this particular part of the system to each individual load for this particular part of the system. Circuits arranged in this manner for distributing the electrical energy to motors inside a building are shown in Fig. 14. The radial arrangement of circuits is used very seldom. Sometimes it is possible to employ it under the following conditions: in interior wiring for supplying large motors, in transmission systems for supplying scattering groups of loads, and in distribution systems for supplying large industrial plants.

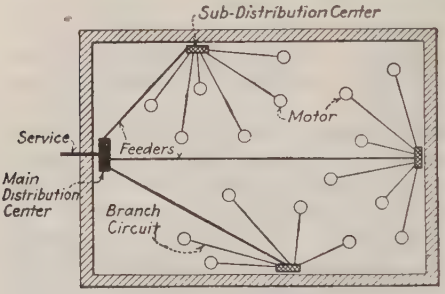


FIG. 15.—Radial-group layout of circuits.

21. A radial-group system of laying out the circuits (Fig. 15) is similar to the radial system except that there is a separate feeder for each group of loads instead of a separate circuit from the source of supply to each individual load. All the individual loads supplied by any one feeder are tapped off from the feeder at one common point called the distribution center. This arrangement of circuits is frequently used for interior wiring supplying motor loads, and occasionally for lighting also. Sometimes it is employed in the distribution system.

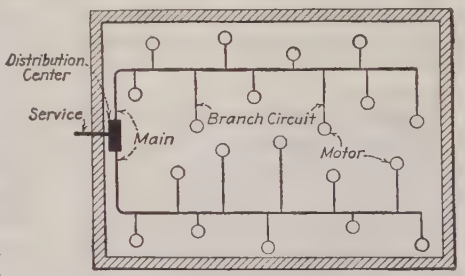


FIG. 16.—Tree layout of circuits.

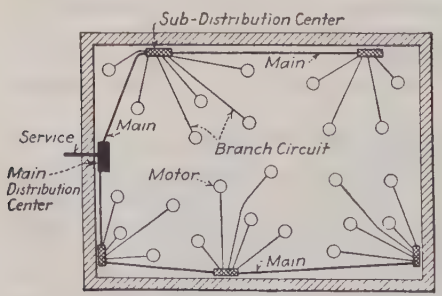


FIG. 17.—Combination of radial-group and tree layout of circuits.

22. In a tree arrangement of the circuits a main is run from the source of energy, with the different loads tapped off at various points along the circuit (Fig. 16). Such a system is commonly employed for distributing the power to motors in the interior of buildings. It is also the method most frequently used by central-station companies for distributing the energy to consumers in

residential districts. Large industrial plants frequently use this system for distributing the energy from the substation to the different buildings.

23. Many wiring systems are a combination of the tree and group systems of arrangement. As in the tree system, loads are tapped off at various points along a main which is run from the source of supply. The loads are divided into several groups, a group of loads being tapped off at a common point on the main (see Fig. 17). Most interior-lighting installations are laid out in this manner. It is used frequently for the layout of the circuits in interior wiring for motors. Frequently, systems of this general nature are employed in large industrial plants for the distribution system from the substation to the different buildings.

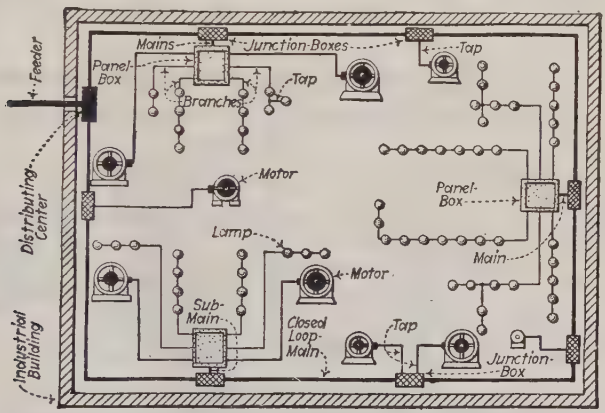


FIG. 18.—Diagram showing "closed-loop main." Each single line represents a circuit.

24. With the ring or loop system, a main is run in the form of a loop from the source of supply around a certain area and back to the source of supply so as to form a closed ring (see Fig. 18). Such a system sometimes is used in both the transmission and the distribution portions of the system and, occasionally, for supplying motors inside industrial buildings.

25. The network arrangement is really an elaborate loop system consisting of a loop tied together at intermediate points. It is the method most frequently employed by central-station companies in their transmission systems and for distribution systems in heavily loaded districts. It is used also for load-center power-distribution systems in industrial plants (refer to Sec. **399,** Div. 9).

ELECTRICAL SYSTEMS

26. Electrical Systems.—There are several systems that may be used for distributing electrical energy over the various arrangements of circuits previously described. They are as follows:

1. Direct-current, two-wire (Fig. 19).
2. Direct-current, three-wire (Fig. 20).
3. Single-phase, two-wire (Fig. 19).
4. Single-phase, three-wire (Fig. 20).
5. Two-phase, four-wire (Fig. 22).
6. Two-phase, three-wire (Fig. 23).
7. Two-phase, five-wire (Fig. 24).
8. Three-phase, three-wire (Fig. 25).
9. Three-phase, four-wire (Fig. 26).

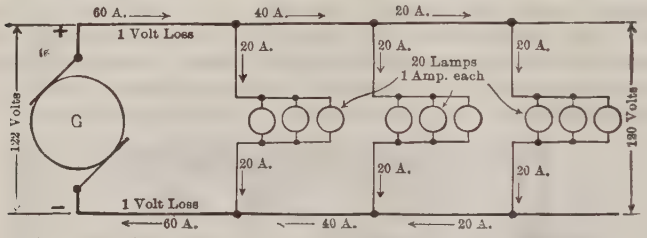
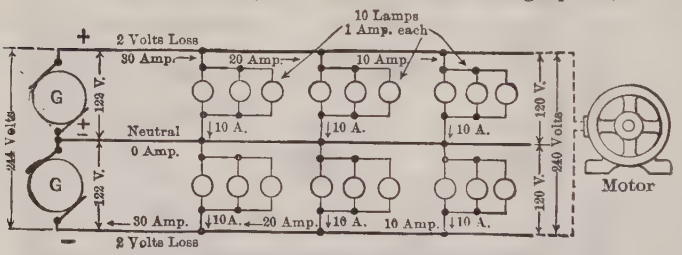
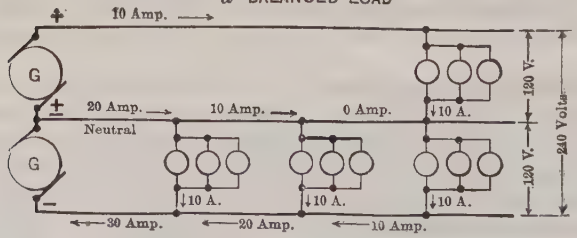


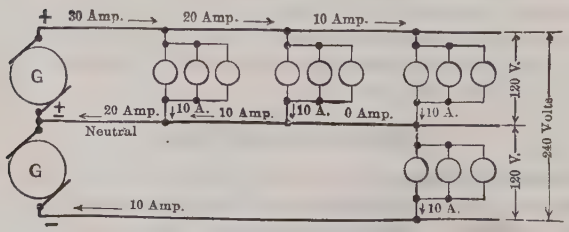
FIG. 19.—Two-wire system (direct-current or single-phase).



a - BALANCED LOAD



b - UNBALANCED LOAD



c - UNBALANCED LOAD

FIG. 20.—Three-wire system (direct-current or single-phase).

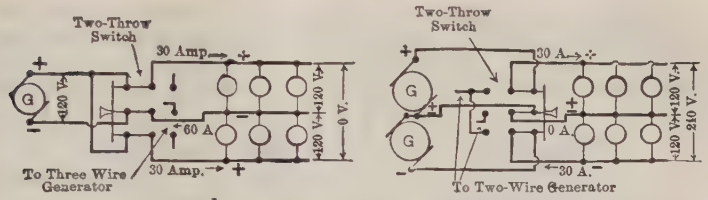


FIG. 21.—Three-wire convertible system (direct-current or single-phase). *a*. Connections when operating three-wire. *b*. Connections when operating two-wire. It is important, in the case of arc lamps and Cooper Hewitt lamps, that they shall all be connected on the side of the circuit which does not reverse polarity when operating two-wire.

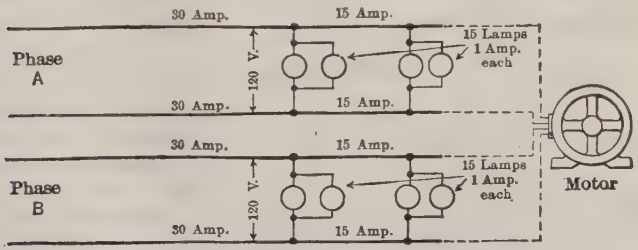
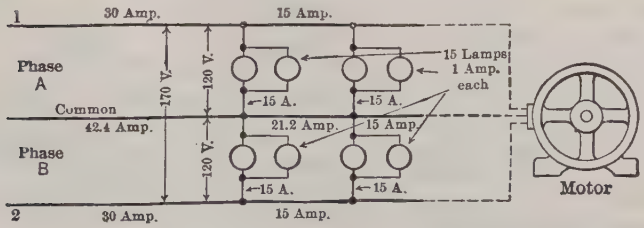
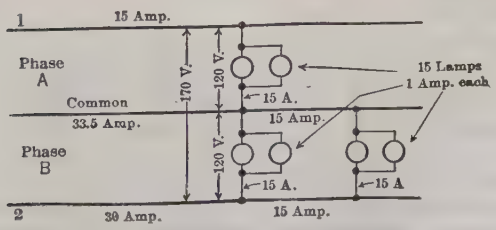


FIG. 22.—Two-phase, four-wire system.



a-BALANCED LOAD



b-UNBALANCED LOAD

FIG. 23.—Two-phase, three-wire system.

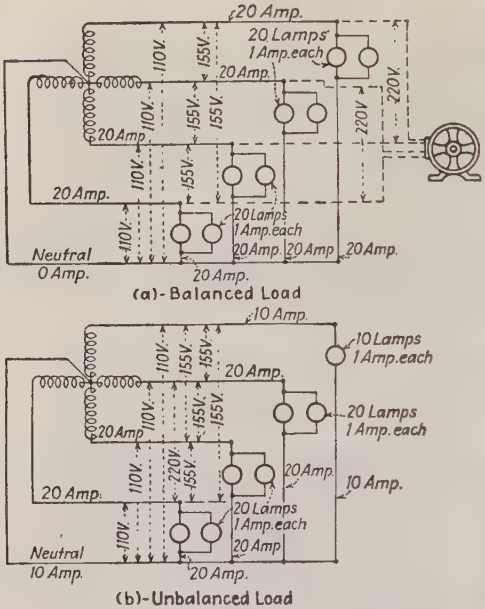


FIG. 24.—Two-phase, five-wire system.

It is generally not good practice to supply lamps and motors from the same circuit (unless the motors are small, fractional-horsepower sizes) for the following reasons:

1. When motors are started, the large starting current causes a voltage drop on the feeder, which will make the lights grow dim or blink.

2. Overloads and short circuits are more common on motor circuits and should not be the cause of putting the lights out.

3. Lamps for satisfactory service must operate within closer voltage limits than motors, and therefore the circuits must be designed for less voltage drop than is allowable on motor circuits.

4. Frequently it is more economical to operate motors on a higher voltage than that of the lighting circuit.

In installations where bus way wiring is employed, it is often very satisfactory to have a common motor and lighting bus for the feeders and mains. These systems if properly planned with generous allowance in the size of the busses will overcome the above criticisms of the common system and provide a very economical installation.

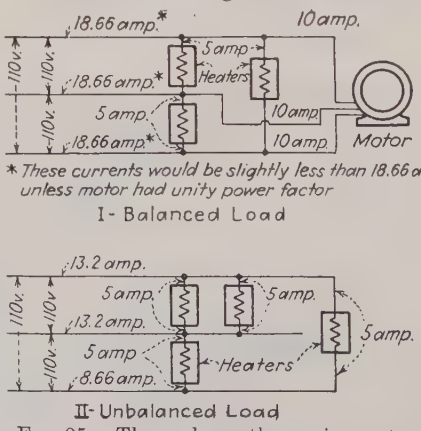
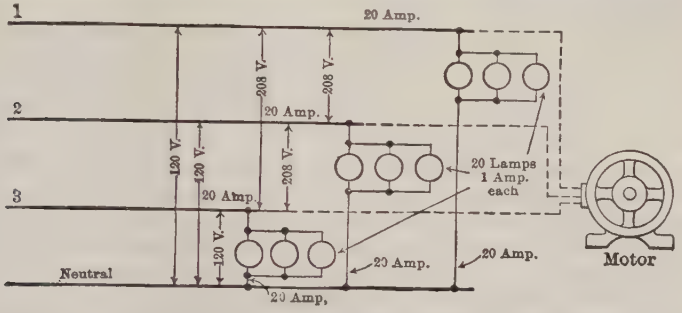
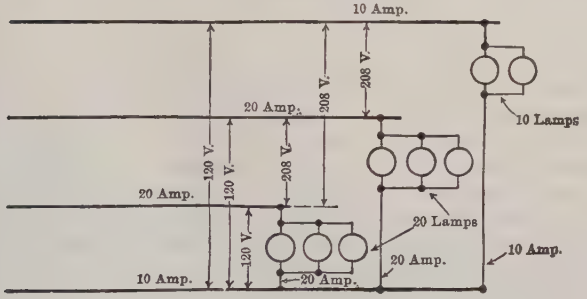


FIG. 25.—Three-phase, three-wire system.

In the illustrations of the various systems, motors and lamps are shown connected to the same circuits simply to indicate the manner in which the



a - BALANCED LOAD



b - UNBALANCED LOAD

FIG. 26.—Three-phase, four-wire system.

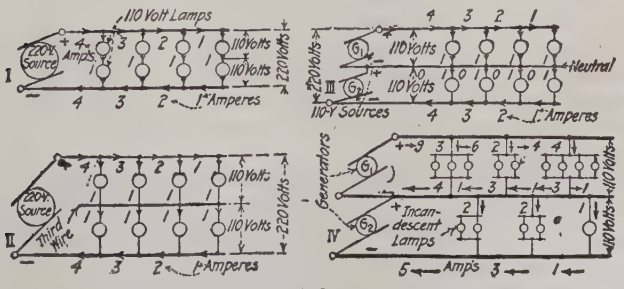


FIG. 27.—Elements of the three-wire system.

different loads would be connected to that type of circuit. The reader is cautioned against forming the impression that they should be connected to the same circuit except in special cases. Considering any one of the

illustrations, if one were dealing with a motor circuit, the lamps should be eliminated from the figure or, vice versa, if dealing with a lighting circuit, the motors should be eliminated.

27. The three-wire, d-c, or single-phase, a-c system is used because it saves copper (see Figs. 20 and 27). Incandescent lamps for 110 to 120 volts are more economical than those for higher or lower voltages. A system of any consequence operating at 110 volts would require very large conductors to maintain the line drop within reasonable limits. With the three-wire system, a low voltage, say 110, is impressed on the receivers while one twice as great, say 220, is used for distribution. Since the weight of conductors for a given power loss varies inversely as the square of the voltage, it is evident that a considerable saving is possible with the three-wire system. In this country the three-wire system is of most importance as applied to 110/220-volt lighting systems.

28. The principle of the three-wire, d-c, or single-phase, a-c system is illustrated in Fig. 27. Incandescent lamps for 110 volts could be connected two in series across 220 volts as shown at I, and, although each lamp would operate at 110 volts, the energy to the group would be transmitted at 220 volts and the outside conductor could, with equal loss, be one-fourth the size that would be necessary if the energy was transmitted at 110 volts. This arrangement (Fig. 27, I), although it would operate, is not commercially feasible because each lamp of each pair of lamps in series must be of the same size, and if one lamp goes out its partner is also extinguished. These disadvantages might be partially corrected by running a third wire as at Fig. 27, II. Then one lamp might be turned off and the others would burn and a single lamp might be added to either side of the system between the third wire and either of the outside wires. But unless the total resistance of all the lamps connected to one side was practically equal to that of all the lamps connected to the other side, the voltage across one side would be higher than that across the other. On the high side the lamps would burn bright and on the low side dim. Obviously, it is not feasible in practice to arrange or "balance" the sides so that they will have the same resistance. Hence some other method must be used in practicable three-wire systems whereby the electricity will be transmitted at, say, 220 volts, and the pressure across the lamps will be, say, 110 volts.

29. Commercial three-wire, d-c, or single-phase, a-c systems consist (Fig. 27, III and IV) of two outer conductors, having (for lighting installations) a pressure of 220 volts impressed across them and a neutral wire so connected to sources of voltage that the pressure between it and either of the outside wires is 110 volts. In Fig. 27, III, generators are the sources of voltage. The neutral wire joins at the point where the generators are connected together. When the system is perfectly balanced, the neutral wire carries no current and the system is in effect a 220-volt system.

Perfect balance seldom obtains in practice. When the balance is not perfect, the neutral wire conveys a current equal to the difference between the current taken by one side and that taken by the other side. Note from Fig. 27, IV, that the current in different parts of the neutral wire may be different and that it is not necessarily in the same direction in all parts of the neutral wire. Each incandescent lamp in Fig. 27, IV, is assumed to take 1 amp., and the small figures indicate the currents in different parts of the circuit.

30. Comparisons of Systems.—The relative weights of copper required for the different systems are given in Fig. 28. The weight of the copper required for the conductors of a two-wire d-c circuit is assumed for convenience to be 100 per cent. The values, given in the column headed "Relative weights of copper in percentage based on drop," are true for direct current, assuming for all systems equal voltages on the lamps or other receivers, equal amounts of power transmitted, equal voltage drops, and balanced loads. For a-c circuits the values are true for circuits where the effect of inductance is negligible. For a-c circuits where the effect of inductance is not negligible, the amount of copper to produce the same voltage drop would be somewhat larger than the values shown in the table. The values given in the last column are based on the assumption that the carrying capacity of a wire is directly proportional to its cross-sectional area. Since the larger the wire, the smaller is the allowable carrying capacity per unit of cross-sectional area, the percentages for systems of more than two wires would be somewhat less than shown. The actual saving in dollars gained by one of the systems that employs more than two wires will not be so great as that indicated in the table, owing to the fact that the total cost for a single large wire is less than for two small wires containing the same total amount of copper.

31. Application of Alternating Current and of Direct Current for Distribution.—The following suggestions are general and cannot be expected to apply to every special case. Where a small amount of power is to be distributed for lighting only and not at a greater distance than about 1 mile from the generating station, direct current will probably be more satisfactory and economical. If many adjustable-speed motors are to be served by a distribution system, the d-c system should be considered. Adjustable-speed, a-c motors are more expensive and do not give such satisfactory results as the d-c shunt motor with field control.

Where electricity is to be distributed to points more than 1 mile distant from the station, alternating current will usually be more economical and satisfactory. It may be generated at a reasonably high voltage and transmitted to the points where it is to be used at that voltage and there "stepped down" with transformers to the voltage required by the receivers. Transmitting at a high voltage makes possible the use of small feeder conductors. Where many constant-speed motors are to be used,

polyphase alternating current is always preferable for either short or long distribution distances because polyphase constant-speed motors are

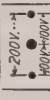
System	Connections	Voltage relations	Relative weights of copper in percentage based on voltage drop	Relative weights of copper in percentage based on carrying capacity
Two-wire, d-c or single-phase	Fig. 19		100	100
Three-wire, d-c or single-phase	Fig. 20		With neutral same size as outside conductors 37.5 With neutral 0.70 the size of the outside conductors 34	With neutral same size as outside conductors 75 With neutral 0.70 the size of the outside conductors 67.5
Three-wire, convertible, d-c or single-phase	Fig. 21		Neutral double size of outside conductors 100	Neutral double size of outside conductors 100
Two-phase, four-wire	Fig. 22		100	100
Two-phase, three-wire	Fig. 23		Common 1.41 times as large as outside conductors 73	Common 1.41 times as large as outside conductors 85
Two-phase, five-wire	Fig. 24		With common 1.41 times as large as outside conductors 34 With common same size as outside conductors 31.3	With common 1.41 times as large as outside conductors 67 With common same size as outside conductors 62.5
Three-phase, three-wire	Fig. 25		75	87
Three-phase, four-wire	Fig. 26		With neutral same size as outside conductors 33.3 With neutral 0.70 as large as outside conductors 31	With neutral same size as outside conductors 67 With neutral 0.70 as large as outside conductors 62

FIG. 28.—Copper economics of different electric systems.

simpler, cheaper, and more reliable than those used on direct current. Furthermore, a-c motors can be operated on higher voltages than can d-c

motors, so it is not necessary to step down for them unless the voltage of the generator is quite high. Two-wire (single-phase) electric lighting can always be arranged from single-phase or polyphase a-c circuits.

Alternating current is always used where it is necessary to transform from one voltage to another without the use of moving apparatus and offers a very flexible system in this respect. But where transformers are used there are slight losses in them even when they are not loaded. An a-c system also has the disadvantages that its inherent voltage regulation and its efficiency are not so good as those of a d-c system. This is particularly true if much inductive equipment, for example, that containing coils wound on iron such as motors and arc lamps, is connected to the circuits. Despite these disadvantages, experience has shown that alternating is preferable to direct current for the applications outlined above. Polyphase constant-speed motors are preferable to d-c constant-speed motors because they are simpler, in that they have no commutator and cost less to maintain than do d-c motors. Direct current is nearly always used in office buildings served by isolated plants because such loads are mainly lighting.

When the main system is alternating current, conversion by means of motor generator sets, rectifiers, and, in special cases, converters may be justified where the load requires special characteristics, such as extra-wide speed range or severe accelerating or reversing duty.

32. Standard D-c Voltages and Their Applications

Voltages		Applications
Generators and energy-delivering apparatus	Motors and energy-utilization apparatus	
125[a]	110	Used for multiple-circuit, incandescent lighting. Usually obtained from a 110/220-volt, three-wire system
125[a]–250[a] 575–600[a]	110 –220 115[a]–230[a] 550[a]	Direct-current motors
600[a]	.....	Urban and interurban electric railways
1,200 1,500	....	Interurban railways
3,000	.....	Trunk-line railways

[a] Electric Power Club standard voltage ratings.

33. Standard A-c Voltages and Their Applications

Voltage		Application
Generators and energy-delivering apparatus	Motors and energy-utilization apparatus	
120/208	110 110 single-phase motors 110–120 lamps and appliances	Single-phase, used for small motors, lighting, and appliances, usually obtained from a 120/240-volt, three-wire, single-phase system or a three-phase, four-wire system.
240 480 600	220 440 550	Usually three-phase three-wire, used for distribution for power for polyphase motors up to possibly 50 to 60 hp. sizes. 220 volts used occasionally for lamps and heaters.
2,400	2,200	Single phase for primary distribution in residential districts; three-phase, three-wire for polyphase motors greater than about 60 or 100 hp.; feeders for large industrial plants.
2,400/4,160	2,300/4,000	For three-phase four-wire distribution in moderately heavily loaded districts.
6,900 11,500 13,800 18,000	6,600 11,000 13,200	Highest voltages for which generators or motors can, ordinarily, be effectively designed. Distribution systems for large cities; for power transmission over distances of a few miles. For high-voltage distribution feeders in industrial plants and large office buildings.
22,000 33,000 44,000 66,000 88,000 110,000 132,000	The voltages higher than 13,200 are used for transmission only and not for generation or utilization.	For power transmission overhead and underground, for distances up to about 125 miles, selection being roughly on the basis of 1,000 volts per mile of transmission distance.
154,000 220,000 275,000	.....	For long-distance power transmission over aerial lines.

NOTE.—The voltages up to 13,800 have been standardized by the American Standards Association, the National Electrical Manufacturers' Association, and the American Institute of Electrical Engineers. The voltages from 22,000 to 154,000 were standardized by the National Electric Light Association and are in common use by power companies. The 220,000- and 275,000-volt systems have been used on a few transmission lines.

34. Selection of a Frequency.—There are two frequencies now standard in this country: 25 and 60 cycles. A frequency of 50 cycles has been used considerably in Europe and in some installations in this country. All other things being equal, 25 cycles would seem at first sight preferable because there is less inductive effect with it than with a higher frequency. It therefore follows that the inherent voltage regulation of a 25-cycle system is better than that of a 60-cycle system and also that the 25-cycle system is a trifle more efficient. For transmission distances of less than a few miles neither of these factors is of much consequence one way or the other. Alternating current at 25 cycles is not particularly well adapted for electric lighting because a flickering due to the filament cooling down

every half cycle while the current is at a low value is very noticeable and causes eyestrain. At 60 cycles the time of low current values is so short that no flickering is noticeable.

Several years ago, 25 cycles was considered necessary for the satisfactory operation of rotary converters, so most d-c electric traction systems have used a 25-cycle transmission system. All d-c railroad electrifications have also used 25 cycles because of the higher power factor and better commutation of the 25-cycle series motors. Again, it is not economically feasible to build large slow-speed motors for main drives in steel mills and cement plants at 60 cycles, so these types of plants have often adopted 25 cycles. Transformers and most other apparatus, except the motors indicated, are cheaper for 60 cycles, and the time for delivery is shorter.

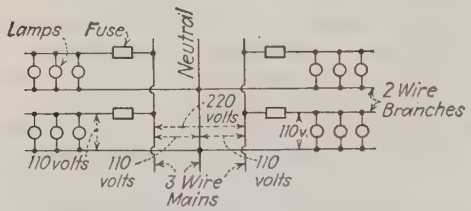
Since 60 cycles is best for most installations, it has become practically the standard frequency in this country, and probably over 90 per cent of the equipment sold here is for 60 cycles. Most of the 50-cycle installations have been or are being changed over to 60 cycles.

35. Table Showing Effect of Increased Voltage and Decreased Voltage on Generators, Lines, Transformers, Meters, Lamps, and Motors.—Sometimes it is necessary or desirable to adopt, for some existing installation, a voltage either higher or lower than that which has been in use. The table indicates the general effects of such a change. The voltage impressed on incandescent lamps should be something between 110 and 120. In new installations, it is well to adopt a high lamp voltage, say about 120. The operating voltage of an old installation may be gradually increased sometimes as much as 10 volts, without adverse results. (*Electrical World*, Sept. 4, 1915.)

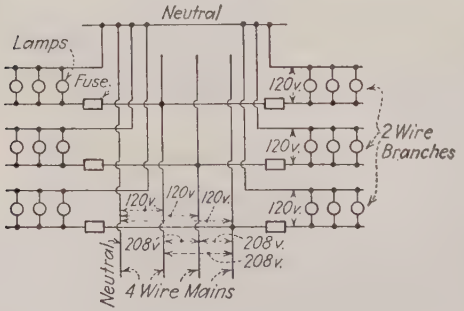
Effect of Increased Voltage on	Effect of Decreased Voltage on
Generators:	Generators:
Increase in excitation.	Decrease in excitation.
Will the exciter voltage be sufficient to produce the required excitation at full load or at partial load of low power factor?	Is the resistance of the field rheostat sufficient to maintain the lower voltage at no load?
Will the fields overheat at the increased excitation required?	Decrease in core loss.
Increase in core loss.	Increase in armature copper loss for the same kilovolt ampere output.
Will the iron overheat?	Will this be offset by the reduction in field and core losses?
Decrease in armature copper loss for same kilovolt ampere output.	
Will this offset the additional field and core loss?	
Lines:	Lines:
Increase in transmission radius for the same kva output.	Decrease in transmission radius for the same kva output.
Transformers:	Transformers:
For the same kva output, increase in core losses, decrease in copper losses, somewhat lower all-day efficiency.	For the same kva output, decrease in core losses, increase in copper losses, somewhat higher all-day efficiency.

Effect of Increased Voltage on	Effect of Decreased Voltage on
Meters:	Meters:
Effect negligible.	Effect negligible.
Lamps:	Lamps:
No effect after the new voltage lamps are installed.	No effect after the new voltage lamps are installed.
Motors:	Motors:
Reduced slip.	Increased slip.
Increased torque.	Decreased torque.
Increased efficiency.	Decreased efficiency.
Decreased power factor of induction motors.	Increased power factor of induction motors.

36. Selection of a Voltage for a Distribution System.—The voltages given in Secs. **32** and **33** are nominal voltages, and it is seldom that apparatus is operated at exactly any one of them. Most power equipment may be operated at any value within 10 per cent below to 10 per cent above the nominal value.



I-Three-Wire Direct Current or Single-Phase Alternating Current



II-Four-Wire, Three-Phase

FIG. 29.—Arrangement of mains and branches for lighting circuits.

Incandescent lamps for 220 volts cost more and are less efficient than the 110-volt ones. This is an inherent condition due to the greater length and smaller diameter of the 220-volt filament, which cannot be corrected. Therefore, a nominal voltage of 110 or 120 (an actual voltage of between 105 and 125) should be used for incandescent lamps. Sometimes the operation of a few lamps on 220 volts with a large 220-volt motor load may be desirable because of the simplicity of the single voltage system and the relative unimportance of the lighting load. But even in this case, a three-phase, four-wire, 120/208-volt system with the lights on the lower voltage and the motors on the higher one would usually be preferable.

Branches serving incandescent lamps (Fig. 29) are usually two wire, but the mains are often three wire or four wire because of the economy in copper of multiwire systems as shown in Fig. 28.

For incandescent lighting or small motors in a building or industrial plant, for distribution distances not exceeding about 1,000 ft., a two-wire, d-c system with a nominal voltage of 110 can be used with fair results. But a three-wire circuit having 220 volts across the outside wires (Fig. 30, I) will usually cost less to install, and it can be used with fair economy for distances up to possibly 1 mile. If the load is almost entirely lighting or adjustable-speed motors, this system is also applicable (Fig. 30, I).

If there is a moderate constant-speed motor load with a fairly large lighting load, a 120/208-volt, three-phase, four-wire a-c system should

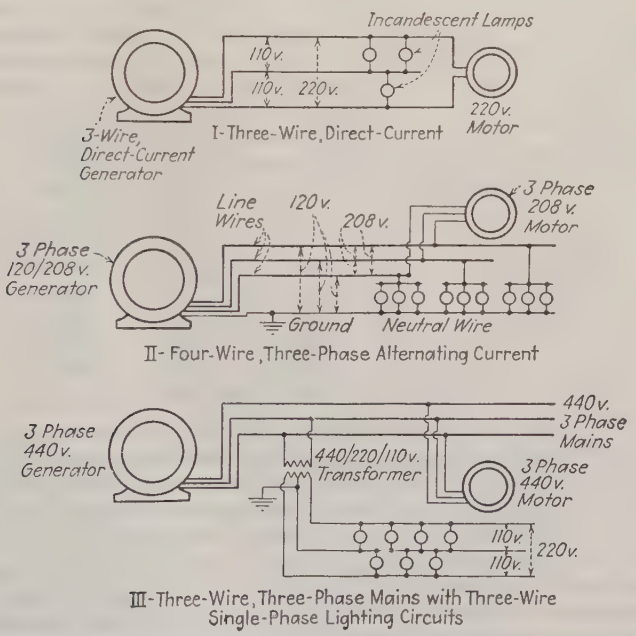


Fig. 30.—Distribution circuits for combination lighting and motor loads.

probably be used. The motors can be operated three-phase, 208 volt (220-volt motors will also operate satisfactorily in most cases). The lighting load can be arranged at 120 volts single-phase between one or all of the line wires and the neutral (Fig. 30, II).

For larger sized motors or a larger total motor load, either a 440- or a 550-volt, three-phase distribution system might profitably be used instead of the 220-volt one, and a saving of about three-fourths of the copper would result. Transformers could be used to provide 110/220-volt, three-wire lighting circuits (Fig. 30, III). However, a voltage exceeding 300 is quite apt to kill a man who comes in contact with it, so, as a rule, 440 volts or greater should not be installed in any plant where the elec-

trical apparatus cannot have expert supervision. A voltage of 440 or 550 volts is low enough so that motors can be conveniently operated at that voltage, and in practice the insulation used on them and on the wires and control apparatus is the same as for 220 volts. Voltages of 440 or 550 find their widest applications in industrial plants and are seldom used in central-station distributions. Direct-current voltages of 550 and over are now seldom used except in street-railway and rapid-transit work and in large adjustable-speed steel-mill drives. See also Sec. **323,** Div. 7.

For industrial plants of any appreciable size, the tendency is toward the use of load-center distribution systems (see Sec. **399,** Div. 9). A three-phase, 2,400- to 13,200-volt distribution system is used outside the buildings. Inside the buildings, high-voltage feeders of the same voltage as the outside distribution system are run to load centers. At the load

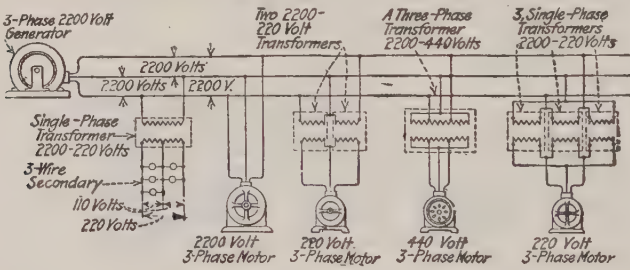


FIG. 31.—A 2,200-volt distribution.

centers, the voltage is stepped down to the desired value for the motor and lighting loads, as indicated in Fig. 31. Transformers stepping down to 120 volts, single-phase or to 120/240 volts, single-phase, three-wire are used for lighting. Three-phase transformers, stepping down to 240, 480, or 600 volts, are used for three-phase constant-speed motors; or, in special cases, 2,200-volt motors are used. If speed control is required, adjustable varying-speed a-c motors or constant-speed motors with variable-speed mechanical drive can be used; or a motor generator or rectifier set can be installed which will deliver direct current at 220 volts for adjustable-speed, d-c motors.

36A. A high distribution voltage is desirable from the standpoint of cost of line conductors because the power lost in a given line, transmitting a given watts load, varies inversely as the square of the impressed voltage. It follows that the weight of a conductor for transmitting a given watts load with a given power loss is inversely proportional to the square of the voltage. If the voltage is doubled, the weight of the conductor is divided by four.

CIRCUIT CALCULATIONS

37. There are five factors that should be considered in determining the size of wire for the distribution of electricity. A wire should be of such

size that (1) the current will not heat it to a temperature that would spoil the insulation or cause a fire, (2) it will have sufficient mechanical strength so that it will not be broken under the ordinary strains to which it is reasonable to assume that it will be subjected, (3) it will not be so large as to exceed the limitations required for its economical installation, (4) it will carry the electricity to the point where it will be used without an excessive drop or loss of voltage, and (5) the cost of energy lost—the I^2R loss—due to the voltage overcoming the resistance will not be excessive (refer to Sec. **88**). A conductor may satisfy any one of the five conditions and not satisfy the four others.

37A. Safe current-carrying capacity should always be considered in designing circuits. When current passes through a conductor, some of the electrical energy is converted into heat energy, the amount of energy thus converted being equal to I^2R (see Div. 1). This heat energy raises the temperature of the conductor and its insulation and covering above that of the surrounding medium and is dissipated into the atmosphere through thermal conduction of the metal of the conductor, conductor insulation and covering, and surrounding materials (such as conduit, ducts, earth, etc.) and through convection of the surrounding air over these materials. It is not good practice to operate bare conductors at a temperature in excess of from 70 to 80°C., since trouble is apt to occur at joints and connections when they are operated at higher temperatures. A curve for determining current capacities of bare copper conductors is given in Sec. **15** of Div. 11. For covered and insulated cables the maximum allowable temperature of the conductor is limited by the maximum temperature that will not be harmful to the insulating and covering materials. Refer to Div. 2 for maximum safe temperatures for different types of insulation. The allowable safe current-carrying capacity of an insulated conductor will therefore depend upon the type of conductor insulation and covering, the conditions of installation (whether in conduit, exposed to air, or buried in earth, and the number of conductors grouped in close proximity to each other), and the temperature of the surrounding atmosphere or earth (ambient temperature). A curve for determining the carrying capacity of weatherproof copper conductors when installed outside buildings is given in Sec. **16** of Div. 11. Curves for aluminum cable, steel-reinforced, are given in Sec. **19** of Div. 11, and a table for parkway cables buried directly in the ground is given in Sec. **20** of Div. 11. It would require more space than is available in this book to include the necessary tables for allowable carrying capacities of cables installed in underground duct systems. Complete tables may be obtained from the various cable manufacturers or from the Insulated Power Cable Engineers Association.

The maximum allowable safe current-carrying capacities of wires for interior wiring are definitely specified by the National Electrical Code (see Tables 17 to 18*B* of Div. 11). The maximum current that a wire will

have to carry should never exceed the allowable safe carrying capacity for the size of wire, type of insulation employed on the wire, and method of installation as given in these tables, except in the case of motor circuits. Motors draw a current at the instant of starting that is much greater than the normal full-load running current. Owing to the fact that this large starting current lasts for only a short time, the Code does not require that the carrying capacity of the wires for motor circuits be as great as the starting current. For branch circuits supplying continuous-duty motors the size of the wire must be sufficient to carry at least 125 per cent of the full-load rated current of the motor. The wires of branch circuits supplying motors in classes of service having short-time duty must have carrying capacities as large as the average load currents required by the motors. In the majority of cases, the average load currents required by motors of this class will not exceed the percentages of the full-load rated currents given in Table 10 of Div. 11. The wires between the slip rings of wound-rotor induction motors and the secondary controller must have a carrying capacity of at least 125 per cent of the full-load secondary current of the motor. The wires between the secondary controller and the resistors must have a carrying capacity that is not less than the percentages of the full-load secondary currents given in Table 10A of Div. 11. The size of wire for motor feeders or mains must be sufficient to carry at least the maximum-demand running current of the motors supplied by the circuit. The method of computing the maximum-demand running current is given in Sec. **60.**

The current-carrying capacities of Tables 19 and 20 of Div. 11 are based upon room temperatures of 30°C. If the room will have a temperature greater than this, the ampere capacities of the table should be multiplied by the proper correction factor as given in the lower parts of the tables.

38. Mechanical Strength of Wires.—Wires should be of sufficient size so that their mechanical strength will be great enough to withstand the strains of installation and of the service to which they will be subjected. For general overhead distribution mains, no wire of soft-drawn copper smaller than No. 6 should be used. If medium- or hard-drawn copper is used, no wire smaller than No. 8 should be employed. For overhead outside wiring on private premises, no wire smaller than No. 10 should be used for spans up to 50 ft. and no wire smaller than No. 8 for longer spans. Service drops from an overhead distribution main to the point of support on the building must not be smaller than No. 10, if of soft-drawn copper, or smaller than No. 12, if of medium- or hard-drawn copper. From the point of support on the building to the service switch inside the building no wire smaller than No. 8 should be used except that, for installations consisting of a single branch circuit, wire as small as No. 12 may be used. For services exceeding 600 volts the service conductors shall not be smaller than No. 6 unless made up in an approved multiconductor, service-entrance cable assembly. For these cable assemblies, no conductor

smaller than No. 8 can be used. In the interior wiring of buildings no wire smaller than No. 14 may be used except for the following special cases:

1. For fixture wiring and flexible cords, Nos. 16 and 18 may be used.
2. Number 18 wire may be used for stationary motors, rated 1 hp. or less, for the conductors between motors or between the motor and an approved terminal enclosure.
3. For elevator wiring the minimum allowable size of conductors is as follows:

a. For lighting circuits, No. 14, except that for flexibility two or more No. 16 conductors may be used in parallel in traveling cables and on the car.
b. For elevator operating and control circuits, No. 16, Type RF-32 or FF-32 fixture wire.
c. For signal circuits and for fixtures, No. 18, Type RF-32 or FF-32 fixture wire.

4. For some cases of low-energy power and signal wiring, No. 18 wire may be used. The National Electrical Code gives detailed rules for these cases.

39. There are certain limitations in the size of wires that it is feasible to employ in order to satisfy construction and installation requirements.

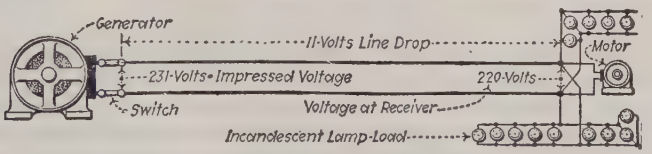


FIG. 32.—Illustrating percentage line drop.

For convenience in installation, it is seldom advisable to use larger than 3-in. conduit. When all the wires of a circuit are run in the same conduit, this limits the size of the conductors to 500,000 cir. mils. If only one wire were run in a conduit the size of wire could be considerably larger. It is seldom wise or convenient to install conductors of larger size than 1,000,000 cir. mils. A 2½-in. conduit is about as large as can usually be installed between floors and ceilings. In such cases, therefore, the size of wire is limited to 300,000 cir. mils, if two or three wires are placed in the same conduit. For open wiring, wires larger than 1,000,000 cir. mils are cumbersome to handle.

40. Percentage line drop or voltage loss may be figured as either a percentage of the voltage required at the receiver or as a percentage of the voltage impressed by the generator or other energy source on the line. For instance, in Fig. 32, the voltage impressed on the receivers—lamps and motor—is 220. The line loss is 11 volts; hence the pressure impressed

on the line = 220 + 11 = 231 volts. The voltage loss as a percentage of the voltage at the receiver = 11/220 = 0.05 = 5 per cent. The voltage loss as a percentage of the voltage impressed on the line is 11/231 = 0.048 = 4.8 per cent. In practical work the percentage loss or drop is usually taken as a percentage of the voltage required at the receivers, because this is the most convenient and direct method. In this book the term percentage drop refers to a percentage of the voltage required at the receivers unless otherwise noted.

41. Allowable Voltage Drops.—The conductors of an interior wiring system should be of sufficient size so that the voltage drop from the point of service entrance to the equipment utilizing the energy, such as lamps or motors, is not excessive. If the voltage drop is too great, the operating conditions will not be satisfactory, owing to one or more of the following causes.

1. Shortened life of lamps caused by overvoltage under light load conditions.
2. Unsatisfactory illumination under maximum load conditions.
3. Unsatisfactory motor speed, torque, or temperature.

No definite standards have been adopted for the maximum allowable voltage drop. The National Electrical Code recommends that the voltage drop from the point of service entrance to the final distribution point should not be greater than 1 per cent for lighting loads or combined lighting and power loads and should not be greater than 3 per cent for power loads.

For **lighting loads** the voltage drop from the point of service entrance to any lamp should not exceed 4 per cent. If it is possible without employing excessively large conductors, it is good practice to keep this total voltage drop within 3 per cent. The voltage drop in any branch lighting circuit or in any lighting feeder should not be greater than 2 per cent.

For **power loads** the voltage drop from the point of service entrance to any motor should not exceed 5 per cent. The distribution of this voltage drop among the different parts of the system will depend upon the layout of the wiring installation. For systems operating at 208 volts or higher, it is generally good practice to limit the voltage drop in motor branch circuits to 1 per cent and in feeders to 4 per cent. Only in exceptional cases should the voltage drop in a motor branch circuit exceed 2 per cent.

Values of voltage drop that will be in accordance with good practice for different systems are given in Sec. **37** of Div. 11.

42. Allowance for Growth in Planning Circuits.—In installing the wiring for electric-power and lighting installations, the demands that may be placed upon the system in the future should be carefully considered. It requires a relatively small additional expense, when installing a system, to put in wires somewhat larger than are required by the present lighting equipment. On the other hand, if the wires installed are of just sufficient

size to accommodate the present load, and it is necessary to increase the load at some future date, the cost of ripping out the old installation and installing a new one is considerable.

Standards of illumination have been continually increasing in the last 10 years, and it is reasonable to assume from the trend of practice that the general level of illuminating intensities employed will be still further increased in the coming few years. Both employees and employers are appreciating more and more the benefits to be gained from high intensities of illumination.

It is, therefore, good practice in most cases to install lighting circuits of sufficient capacity so that they will be large enough if the size of the lamps is increased to the next larger standard size. In the following paragraphs dealing with the calculation of the load on lighting circuits, the term future load means the load that would be placed on the circuit if all the lamps connected to the circuit were increased to the next larger standard size.

The layout and equipment in industrial and commercial buildings are continuously being changed. These changes frequently involve increased load requirements. For these occupancies there are no definite rules that can be laid down for the proper allowance that should be made for growth, since the conditions vary so widely for different installations. Each installation requires careful study with respect to probable future load requirements. The actual connected loads on the circuit should be increased a sufficient amount so that the size of circuit will be ample to accommodate whatever loads it is estimated may be connected to the circuit in the future.

43. Calculation of Load in Amperes on Two-wire, Branch Lighting and/or Appliance Circuits.—The actual load in amperes on a two-wire branch lighting circuit is equal to the sum of the watt ratings of the individual loads connected to the circuit divided by the voltage of the circuit. Each heavy-duty lampholder outlet for lighting other than general illumination should be figured at 5 amp. Each plug receptacle outlet connected to the circuit should be figured at at least 1.5 amp. per outlet. If the load to be connected to a plug outlet is known to be more than 1.5 amp., its load should be considered as the actual known wattage that it will supply.

For show-window lighting a load of not less than 200 watts for each linear foot of show window, measured horizontally along its base, may be allowed in lieu of the 1.5 amp. per outlet. Where fixed multioutlet assemblies are supplied by the circuit, each 5 ft. or fraction thereof of each separate and continuous length of the assembly should be considered as a load of 1.5 amp., except in locations where a number of appliances are likely to be used simultaneously. In that case each 1 ft. or fraction thereof should be considered as a load of 1.5 amp. In computing the load of lighting units that employ ballasts, transformers, or autotrans-

formers, such as fluorescent lighting units, the load must be based on the line current rating of the complete unit, and not on the wattage of the lamps. For fluorescent lamps, line current values can be obtained from the table in Sec. **94A** of Div. 10.

The future load in amperes is figured in the same manner as the actual load, substituting for each lamp one of the next larger standard size. The standard sizes of lamps are given in Table 1 of Div. 11 with more complete data in Div. 10.

Example.—A two-wire, 110-volt, branch lighting circuit supplies five 200-watt lamps. Determine the actual connected and probable future load.

Solution.—Present connected load $= \frac{5 \times 200}{110} = 9.1$ amp.

The next larger standard size of lamps is 300 watts.

Future connected load $= \frac{5 \times 300}{110} = 13.6$ amp.

Example.—A two-wire, 110-volt, branch lighting circuit supplies four 150-watt lamps and three 200-watt lamps. Determine the actual connected and probable future load.

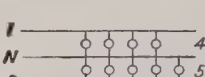
Solution.—Present connected load $= \frac{(4 \times 150) + (3 \times 200)}{110} = 10.9$ amp.

The next larger standard-sized lamp to 150 watt is 200 watt and the next larger to 200 watt is 300 watt.

Future connected load $= \frac{(4 \times 200) + (3 \times 300)}{110} = 15.5$ amp.

44. Calculation of Load in Amperes on Three-wire, Branch Lighting and/or Appliance Circuits.—The actual and future loads in amperes on either side of a three-wire, branch lighting circuit may be computed in the same manner as for two-wire circuits in Sec. **43,** the voltage between the neutral and either outside wire and the loads connected between the neutral and the one outside wire under consideration being used.

Example.—A three-wire, 110- to 220-volt, branch lighting circuit supplies the loads in the following diagram. Determine the actual connected and probable future loads.



Solution.—Present connected load 1 to $N = \frac{4 \times 200}{110} = 7.3$ amp.

Present connected load 2 to $N = \frac{5 \times 150}{110} = 6.8$ amp.

Future connected load 1 to $N = \frac{4 \times 300}{110} = 10.9$ amp.

Future connected load 2 to $N = \frac{5 \times 200}{110} = 9.1$ amp.

45. Calculation of Load in Amperes on Branch Electric-range Circuits.—For electric ranges and other cooking appliances of 1¾-kw rating or less, the load on the branch circuit is equal to the ratings of the appliances. For ranges or cooking appliances of ratings greater than 1¾ kw,

the watt load on the branch may be computed in accordance with Table 2, of Div. 11.

For two-wire branches, the load in amperes is equal to the watt load, as determined above, divided by the voltage of the circuit. For three-wire branches, the load in amperes on each outside wire of the circuit is equal to the watt load, as determined above, divided by the voltage between outside wires. The load in amperes on the neutral wire may be taken as 70 per cent of the load on an outside wire.

46. Calculation of Lighting and Appliance Load on Two-wire, D-c or Single-phase Distribution Panels.—The actual connected load is equal to the sum of the actual connected loads of all the branch circuits fed from the panel. Each spare or appliance circuit in the panel should be figured at at least 10 amp. The future load on the panel is figured in the same manner as the actual load, the future loads of the branch circuits being used instead of the actual loads, and each appliance or spare circuit being figured at at least 15 amp. If an appliance circuit is of a type allowing more than 15 amp., the circuit should be figured at its maximum allowable amperage as given in Div. 9.

Example.—Determine the actual connected and probable future loads on a two-wire, 110-volt lighting panel supplying the following circuits:

Circuit	Present load, amp.	Future load, amp.
1	10	13
2	7	10
3	9	12
4	10	15
5	8	10
6	12	15
7 (spare)	10	15
8 (spare)	10	15
	76	105

Solution.—Present connected load on panel = 76 amp.
Probable future load = 105 amp.

47. Calculation of Lighting and Appliance Load on Three-wire, D-c or Single-phase Distribution Panels.—The actual connected load on each side of the panel is computed in the same manner as for two-wire panels in Sec. **46**, using the voltage between the neutral and one outside wire and making separate calculations for each line wire. If the circuits have been well laid out there should not be much difference between the loads on the two sides of the panel.

Example.—A three-wire, 110- to 220-volt lighting panel supplies the following circuits. All branch circuits are two wire, 110 volts. Determine the actual connected and the probable future loads.

Branch circuits between wire 1 and neutral			Branch circuits between wire 2 and neutral		
Circuit	Present load, amp.	Future load, amp.	Circuit	Present load, amp.	Future load, amp.
1	7	9	1	6	8
2	8	10	2	7	10
3	8	10	3	6	9
4	7	10	4 (plug)	10	15
5 (plug)	10	15	5 (spare)	10	15
6 (spare)	10	15	6 (spare)	10	15
	50	69		49	72

Solution.—The present connected load would be taken as 50 amp. The future load would be taken as 72 amp.

48. Calculation of Lighting and Appliance Load on Two-phase, Three-wire Distribution Panels.—The loads for the two-line wires are computed as in Sec. **47.** The actual and future loads on the common wire of the panel are taken as equal to 1.41 times the actual and future loads, respectively, of the more heavily loaded side of the panel.

Example.—A three-wire, two-phase, 110-volt lighting panel supplies the same circuits on the two sides of the panel as given in the example under the three-wire, single-phase panel. Determine the actual connected and probable future loads.

Solution.—The actual connected load on each outside wire of the panel would be taken as 50 amp.

The future load on each outside wire of the panel would be taken as 72 amp.

The actual connected load on the neutral would be $1.41 \times 50 = 70.5$ amp.

The future load on the neutral would be $1.41 \times 72 = 101.5$ amp.

49. Calculation of Lighting and Appliance Load on Four-wire, Three-phase Distribution Panels.—The actual connected load on any one bus except the neutral bus is computed as in Sec. **47.** The load on each of the four busses usually is taken as being equal to that of the most heavily loaded outside bus.

50. Fundamentals of Load Calculations on Mains and Feeders.—In many cases the carrying capacity of feeders or mains need not be so great as the total ampere load of all the equipment supplied by the circuit. This is due to the fact that all the apparatus may not be operating at the same time, or, if operating, may not all be taking full-load current from the line at the same time. A demand factor is employed in order to determine the maximum current that it is estimated the circuit will ever

be required to carry. A demand factor is the ratio between the maximum current that the circuit will ever have to carry and the total load connected to the circuit. The maximum-demand current of a circuit, therefore, is equal to the total connected load times the proper demand factor (see Table 3, Div. 11, for lighting demand factors; Table 5, Div. 11, for maximum-demand factors for motor circuits; and Table 2, Div. 11, for demand factors for household electric ranges). Where four or more fixed appliances, in addition to an electric range or ranges, are connected to the same feeder or main in a single or multifamily dwelling, a demand factor of 75 per cent may be applied to the fixed-appliance load, not including the electric ranges.

51. Calculation of Load on Two-wire D-c or Single-phase A-c Lighting and Appliance Feeders or Mains.—The ampere load is equal to the sum of the maximum-demand lighting and portable-appliance load, the maximum-demand fixed-appliance load, and the maximum-demand electric-range load. The present or future maximum-demand lighting and portable-appliance load is equal to the sum of the actual or future lighting and portable-appliance loads of all the panels fed from the circuit times the proper demand factor as determined from Table 3, Div. 11. The maximum-demand fixed-appliance load is figured in accordance with Sec. **50**. The maximum-demand electric-range load is figured in accordance with Table 2, Div. 11.

Example.—A two-wire, single-phase lighting feeder supplies the following three panels in an apartment house. Determine the actual and future loads on the circuit.

Panel	Actual load, amp.	Future load, amp.	Area fed by panel, sq. ft.
A	50	75	3,000
B	60	80	4,000
C	45	60	4,000
	155	215	11,000

From Table 3, Div. 11, the demand factor on the first 2,000 sq. ft. is 1.0, and the demand factor on the area in excess of 2,000 sq. ft. is 0.35.

Amount of present load on first 2,000 sq. ft. $= \left(155 \times \frac{2{,}000}{11{,}000}\right) \times 1.0 = 28$

Present load on area in excess of 2,000 sq. ft. $= \frac{155 \times 9{,}000}{11{,}000} \times 0.35 = 44.5$

Total present load $= \overline{72.5}$

Future load on first 2,000 sq. ft. $= \frac{215 \times 2{,}000}{11{,}000} \times 1.0 = 39.1$

Future load on area in excess of 2,000 sq. ft. $= \frac{215 \times 9{,}000}{11{,}000} \times 0.35 = 61.6$

Total future load $= \overline{100.7}$

52. Calculation of Load on Three-wire, D-c or Single-phase A-c Lighting and Appliance Feeders or Mains.—The ampere load on either outside wire is equal to the sum of the maximum-demand lighting and portable-appliance load, the maximum-demand fixed-appliance load, and the maximum-demand electric-range load fed from that wire. The present or future maximum-demand lighting and portable-appliance load is equal to the sum of the actual or future lighting and portable-appliance loads of all the panels fed from that wire times the proper demand factor as determined from Table 3, Div. 11. The maximum-demand fixed-appliance load is equal to the sum of all the fixed-appliance load fed from that wire times the proper demand factor as given in Sec. **50.** The maximum-demand current for the electric-range load is equal to the maximum-demand watt range load as determined in accordance with Table 2, Div. 11, divided by the voltage between outside wires of the circuit.

The ampere load on the neutral wire is equal to the ampere load on the more heavily loaded outside wire, when that current is 200 amp. or less. If the load on either of the outside wires is more than 200 amp. the current in the neutral wire may be taken as 200 amp. plus 70 per cent of the current in the more heavily loaded outside conductor in excess of 200 amp.

Example.—A three-wire, 115/230-volt main in an office building of 10,000 sq. ft. supplies the following loads: 77.2 amp. actual connected and 97.0 amp. future load on one side of the feeder, and 80.3 amp. actual connected and 95.1 amp. future load on the other side of the feeder. Determine the present and future loads on the feeder.

Solution.—Since the area is just 10,000 sq. ft., the demand factor from Table 3, Div. 11, is 1.0.

Present load on one outside wire = $77.2 \times 1.0 = 77.2$ amp.

Present load on other outside wire = $80.3 \times 1.0 = 80.3$ amp.

Future load on one outside wire = $97.0 \times 1.0 = 97.0$ amp.

Future load on other outside wire = $95.1 \times 1.0 = 95.1$ amp.

Since the larger current in an outside wire is less than 200, the load on the neutral will be the same as that of the more heavily loaded outside wire.

Present load on neutral = 80.3 amp.

Future load on neutral = 97.0 amp.

Example.—The actual connected load on the more heavily loaded side of a three-wire, 115/230-volt, single-phase feeder in an office building of 15,000 sq. ft. is 250 amp. Determine the present load on the neutral.

Solution.—From Table 3, Div. 11, the demand factor on the first 10,000 sq. ft. is 1.0, and on the area in excess of 10,000 sq. ft. is 0.70.

$$\text{Present load on outside wire} = \left(\frac{250 \times 10{,}000}{15{,}000} \times 1.0\right) + \left(\frac{250 \times 5{,}000}{15{,}000} \times 0.7\right)$$
$$= 166.7 + 58.4 = 225.1 \text{ amp.}$$

Since the current in the outside wire, after applying the demand factor, is greater than 200 amp., the present load on the neutral will be $200 + (25.1 \times 0.70) = 217.6$.

53. Calculation of Load on Four-wire, Two-phase Lighting and Appliance Feeders or Mains. –The ampere loads on either phase may be computed as in Sec. **51,** considering each phase as a separate single-phase circuit.

54. Calculation of Load on Three-wire, Two-phase Lighting and Appliance Feeders or Mains.—For the two-line wires proceed as in Sec. **52.**

The load on the common wire is equal to 1.41 times the load on the more heavily loaded outside wire, when that current is 200 amp. or less. If the load on either of the outside wires is more than 200 amp., the current in the common wire may be taken as 200 amp. times 1.41 plus the current in the more heavily loaded outside wire in excess of 200 amp.

Example.—Determine the present and future loads for a three-wire, two-phase feeder in an industrial building of 9,000 sq. ft. supplying the following loads:

Panels connected between wire 1 and common wire			Panels connected between wire 2 and common wire		
Panel	Present load, amp.	Future load, amp.	Panel	Present load, amp.	Future load, amp.
A	50.8	65.2	*A*	47.8	61.3
B	43.7	55.6	*B*	52.7	67.9
C	41.4	54.7	*C*	36.8	45.9
	135.9	175.5		137.3	175.1

Solution.—From Table 3, Div. 11, the demand factor is 1.0.
Present load on wire 1 = 135.9 × 1.0 = 135.9 amp.
Future load on wire 1 = 175.5 × 1.0 = 175.5 amp.
Present load on wire 2 = 137.3 × 1.0 = 137.3 amp.
Future load on wire 2 = 175.1 × 1.0 = 175.1 amp.
Present load on common wire = 137.3 × 1.41 = 193.6 amp.
Future load on common wire = 175.5 × 1.41 = 248 amp.

55. Calculation of Load on Five-wire, Two-phase Lighting and Appliance Feeders or Mains.—For the four line wires proceed as for the line wires in Sec. **52.** For the neutral proceed as for the common wire in Sec. **54.**

Example.—The actual connected loads on the four outside wires of a five-wire, two-phase lighting feeder are 100.5, 97.8, 95.4, and 100.0 amp. The feeder is supplying the load in a factory building. Determine the present load for the neutral wire.

Solution.—From Table 3, Div. 11, the demand factor is 1.0. Since the current in the most heavily loaded outside wire (100.5 × 1.0) is less than 200, the load on the neutral = (100.5 × 1.0)1.41 = 142 amp.

Example.—The actual connected load of the most heavily loaded outside wire of a five-wire, two-phase lighting feeder is 356 amp. The feeder supplies an office building of 40,000 sq. ft. Determine the load on the neutral.

Solution.—From Table 3, Div. 11, a demand factor of 1.0 for the load on the first 10,000 sq. ft., and of 0.70 for the load on all area in excess of 10,000 sq. ft. should be used.

The actual connected load on the first 10,000 sq. ft. $= 356 \times \frac{10{,}000}{40{,}000} = 89$

The actual connected load on the area in excess of 10,000 sq. ft. $= 356 \times \frac{30{,}000}{40{,}000} = 267$

The load on the most heavily loaded outside wire $= (89 \times 1.0) + (267 \times 0.70) = 276$ amp. Since the load on the most heavily loaded outside wire is greater than 200, the load on the neutral $= (200 \times 1.41) + (276 - 200)$
$= 358$ amp.

56. Calculation of Load on Four-wire, Three-phase Lighting and Appliance Feeders or Mains.—The ampere load on any outside wire is computed as in Sec. **52,** except for the calculation of the maximum-demand current for the electric-range load. The maximum-demand current for the range load should be determined from the following formula:

$$\text{Maximum-demand range current} = \frac{\text{watt load as determined from Table 2, Div. 11, for twice the number of ranges connected between any two outside wires}}{2 \times (\text{voltage between an outside wire and neutral})} \quad (1a)$$

For the ampere load of the neutral wire, proceed as for the neutral in Sec. **52.**

Example.—The actual connected load on the most heavily loaded outside wire of a lighting feeder supplying a hotel with an area of 60,000 sq. ft. is 378 amp. There are no provisions for individual cooking. Determine the proper present load to allow on the neutral wire.

Solution.—From Table 3, Div. 11, the following demand factors should be used: 0.5 for load on first 10,000 sq. ft., 0.4 for load on area between 10,000 and 50,000 sq. ft., 0.3 for load on area in excess of 50,000 sq. ft.

Actual connected load for first 10,000 sq. ft. $= \frac{378 \times 10{,}000}{60{,}000} = 63$

Actual connected load for area between 10,000 and 50,000 sq. ft. $= \frac{378 \times 40{,}000}{60{,}000} = 252$

Actual connected load for area in excess of 50,000 sq. ft. $= \frac{378 \times 10{,}000}{60{,}000} = 63$

Present load on most heavily loaded outside wire $= (63 \times 0.5) + (252 \times 0.4) + (63 \times 0.3)$
$= 31.5 + 100.8 + 18.9 = 151.2$

Present load on neutral $= 151.2$

57. Determining Size of Lighting and Appliance Distribution Panel Busses.—The required ampere capacity of the busses in lighting and appliance distribution panels can be calculated in the same manner as given in the preceding sections for the calculation of the ampere loads on feeders and mains.

58. Minimum Allowable Load to Use for Any Lighting Feeder or Main.—The National Electrical Code specifies definite rules for comput-

ing the minimum loads for a given area. Feeders or mains must be of sufficient size to carry safely at least the amperes required by these rules regardless of the actual connected load. The areas employed in applying the rules should be gross floor areas as determined from the outside dimensions of the building and the number of floors. Floor areas of open porches, garages in connection with dwelling occupancies, and unfinished and unused spaces in dwellings, unless adapted for future use, need not be included.

The minimum allowable watt load for the feeder or main supplying power to any area for lighting and appliances must be equal to the sum of the minimum allowable general-lighting load, the portable-appliance load, the fixed-appliance load (other than ranges), and the electric-range load. The minimum allowable general-lighting load is equal to the area times the minimum allowable watts per square foot for that type of area times the proper demand factor. The minimum allowable watts per square foot and the allowable demand factors for different types of areas are given in Table 4 of Div. 11. The portable-appliance load requirements are given in Table 4 of Div. 11. Where in normal operation the load on the installation will continue for long periods of time, such as in store lighting, the minimum allowable load, as determined above, must be increased by 25 per cent. The fixed-appliance load is equal to the summation of the watt rating of the actual fixed appliances installed in the area, where the number of such appliances is four or less. For electric ranges and other cooking appliances of $1\frac{3}{4}$ kw. rating or less, a load equal to the summation of the watt ratings of the ranges or appliances installed must be included. For electric ranges and other cooking appliances rated more than $1\frac{3}{4}$ kw. the minimum allowable load may be computed from Table 2 of Div. 11. Where a number of ranges are supplied by a three-phase, four-wire feeder, the minimum allowable watt load should be computed from the following formula:

$$\text{Minimum allowable range watt load} = 3 \times \frac{\text{watt load as determined from Table 2 of Div. 11 for twice the number of ranges connected between any two outside wires}}{2} \qquad \text{(1b)}$$

The minimum allowable load for motor circuits is identical with the values obtained from the instructions of Secs. **59** and **60.**

The minimum allowable load for circuits supplying both motors and other loads is equal to the motor load plus the minimum allowable load of other types. After the minimum allowable watt load has been determined, the corresponding ampere load may be determined from the following formulas and instructions, depending upon the type of electric system employed.

$$I = \frac{\text{minimum allowable watts}}{KE} \quad (2)$$

where K = 1 for two-wire d-c; or two-wire, single-phase a-c.
= 1.73 for three-wire, three-phase a-c.
= 2 for three-wire d-c; three-wire, single-phase a-c; three-wire, two-phase a-c; or four-wire, two-phase a-c.
= 3 for four-wire, three-phase a-c.
= 4 for five-wire, two-phase a-c.

and E = voltage between outside wire and neutral if the system has a neutral; otherwise the voltage between any two line wires.

and I = current in any line wire except the neutral.

Neutral for three-wire, d-c; three wire, single-phase, a-c; or four-wire, three-phase:

When current in outside wires is 200 amp. or less

$$I_n = \text{current in outside wire} \quad (3)$$

When current in outside wires is greater than 200 amp.

$$I_n = 200 + (0.70 \times \text{current in outside wire} - 200) \quad (3a)$$

Neutral for three-wire or five-wire, two-phase:

When current in outside wires is 200 amp. or less

$$I_n = 1.41 \times (\text{current in outside wire}) \quad (4)$$

When current in outside wires is greater than 200 amp.

$$I_n = (200 \times 1.41) + (\text{current in outside wire in excess of 200 amp.}) \quad (4a)$$

Example.—Determine the minimum allowable loading of a feeder supplying a multi-family dwelling having an area of 30,800 sq. ft. with 44 apartments.

Solution.—From Table 4, Div. 11, 3.0 watts must be allowed for each square foot plus 1,500 watts for appliances for each apartment. The demand factor from Table 4 of Div. 11 is 1.0 for the first 3,000 watts, 0.35 for the next 117,000 watts, and 0.25 for all load in excess of 120,000 watts.

Lighting load = 3 × 30,800 = 92,400
Appliance load = 44 × 1,500 = 66,000
Total load based on area = 158,400 watts
Minimum allowable watt load = 3,000 + (117,000 × 0.35) + (158,400 − 120,000)0.25 = 53,550 watts

For a two-wire, 115-volt, single-phase or d-c system:

$$I = \frac{53,550}{115} = 466 \text{ amp.}$$

For a three-wire, 115/230-volt, single-phase or d-c system:

$$I \text{ (outside wires)} = \frac{53,550}{2 \times 115} = 233 \text{ amp.}$$

$$I \text{ (neutral)} = I \text{ (outside wire)} = 233 \text{ amp.}$$

For a four-wire, 115-volt, two-phase system:

$$I = \frac{43{,}610}{2 \times 115} = 189.6 \text{ amp.}$$

For a three-wire, 115-volt, two-phase system:

$$I(\text{outside wires}) = \frac{43{,}610}{2 \times 115} = 189.6 \text{ amp.}$$

$$I(\text{common wire}) = 1.41 \times 189.6 = 267 \text{ amp.}$$

For a five-wire, 115/230-volt, two-phase system:

$$I(\text{outside wires}) = \frac{43{,}610}{4 \times 115} = 94.8 \text{ amp.}$$

$$I(\text{neutral}) = 1.41 \times 94.8 = 134 \text{ amp.}$$

For a four-wire, 120/208-volt, three-phase system:

$$I(\text{outside wires}) = \frac{43{,}610}{3 \times 120} = 121 \text{ amp.}$$

$$I(\text{neutral}) = I(\text{outside wire}) = 121 \text{ amp.}$$

Example.—Determine the minimum allowable loading for a three-wire, 115/230-volt feeder supplying an apartment house having a total floor area of 32,000 sq. ft. with 40 apartments. One-half of the apartments are equipped with electric ranges of 10 kw. each.

Solution.—From Table 4, Div. 11, 3 watts must be allowed for each square foot plus 1,500 watts for appliances for each apartment. The demand factor for the lighting and appliance load from Table 4 of Div. 11 is 1.0 for the first 3,000 watts, 0.35 for the next 117,000 watts, and 0.25 for all load in excess of 120,000 watts. From Table 2 of Div. 11, the maximum demand for the range load is 35 kw.

Lighting load = 3 × 32,000	= 96,000
Appliance load = 40 × 1,500	= 60,000
Total lighting and appliance load	= 156,000 watts
Minimum allowable lighting and appliance load = 3,000 + (117,000 × 0.35) + (156,000 − 120,000)0.25	= 52,950 watts
Range load	= 35,000 watts
Total minimum allowable watt load	= 87,950 watts

$$I \text{ (outside wires)} = \frac{87{,}950}{2 \times 115} = 382 \text{ amp.}$$

$$I \text{ (neutral)} = 200 + (382 - 200)0.70 = 327 \text{ amp.}$$

Example.—Determine the minimum allowable load for a feeder supplying an office building having an area of 100,000 sq. ft.

Solution.—From Table 4, Div. 11, 2 watts must be allowed per square foot. From Table 4, Div. 11, the demand factor is 1.0 for the first 20,000 watts and 0.70 for all load in excess of 20,000 watts.

Watt load based on area = 100,000 × 2 = 200,000 watts
Minimum allowable watt load = 20,000 + (200,000 − 20,000)0.70 = 146,000 watts

For a four-wire, 120/208-volt, three-phase system:

$$I(\text{outside wires}) = \frac{146{,}000}{3 \times 120} = 405 \text{ amp.}$$

$$I(\text{neutral}) = 200 + (405 - 200)0.70 = 343.5 \text{ amp.}$$

59. Calculation of Load on Motor Branch Circuits.—For continuous-duty motors the load on the branch circuit feeding a single motor is taken as 125 per cent of the full-load rated current of the motor. The load on a branch circuit supplying a motor in a class of service having short-time duty depends upon the character of the loading. In the majority of cases the load need not be greater than the percentages of the full-load rated currents given in Table 10 of Div. 11. The average full-load rated currents of the different types and sizes of motors are given in Tables 6 to 9 of Div. 11.

The load on conductors connecting the secondary of a wound-rotor, polyphase induction motor to its controller is taken as 125 per cent of the full-load secondary current of the motor for continuous-duty motors, and not less than the percentages given in Table 10 of Div. 11 of the full-load secondary current for short-time-duty motors. The loads on the conductors connecting the controller with the secondary resistors must be taken at not less than the proper percentage, as given in Table 10*A* of Div. 11, of the full-load secondary current. The value of the full-load secondary current, if not marked on the name plate of the motor, should be obtained from the manufacturer of the motor since its value will depend upon the design of the motor. For preliminary studies the secondary current may be taken equal to the motor full-load line current for values of full-load current up to about 20 amp. For larger motors the secondary current is usually less than the full-load line current. For a motor with a full-load line current of about 50 to 70 amp., the secondary current is about two-thirds of that value; for a full-load line current of about 80 to 120 amp., the secondary current is about one-half of that value; for a full-load line current of about 150 to 250 amp., the secondary current is about one-third the full-load line value.

60. Calculation of Load on Motor Feeders and Mains.—Two values of load should be computed for motor feeders or mains: one the maximum-demand starting current, and the other the maximum-demand running current. The maximum-demand running current may be used in determining the size of wire required to carry the current safely. Although this meets the requirements of the National Electrical Code, many authorities consider it better practice to use the maximum-demand starting current in determining the size of wire according to carrying capacity, since then the circuit can be protected against both straight overload and short circuit. When the maximum-demand running current is used for determining the size of wire according to carrying capacity, the circuit can be protected only against short circuit or very heavy overloads and not against overloads of moderate severity. The maximum-demand running current is used for computing the voltage drop of the circuit. The maximum-demand starting current is employed in determining the proper size of protective equipment for the circuit. Values of the average starting currents of motors are given in Tables 12, 13, and 14 of Div. 11.

The National Electrical Manufacturers' Association (N.E.M.A.) adopted in 1940 a standard of identifying code letters that must be marked by the manufacturers on motor name plates to indicate the motor kilovolt-ampere input with locked rotor. These code letters with their classification are given in Table 12 of Div. 11. At the time of this writing the code letters have not been classified with respect to the types of motors to which each will normally apply. In determining the starting current to employ for circuit calculations, use values from Table 13 of Div. 11 if the motor name plate is marked with the N.E.M.A. identifying code letter; otherwise, use values from Table 14 of Div. 11.

In many installations where the number of motors is greater than five, all the motors would not be running at full load at the same time. It is general practice, therefore, on such feeders or mains to use a maximum-demand factor so that the estimated maximum-demand current is less than the sum of the full-load rated currents of all the motors fed from the circuit. Values of maximum-demand factors that have been found satisfactory for ordinary installations are given in Table 5 of Div. 11 It should be remembered, in applying these demand factors, that they are average values satisfactory for ordinary installations. Before they are used, a careful study of the operating conditions of the plant should be made, in order to determine whether the conditions of instantaneous loading of the motors will come within the average conditions or whether there are some special requirements that will submit the feeders to a greater loading than will be taken care of by these factors.

Permission for the use of a demand factor must be obtained from the authority enforcing the Code. Some authorities recommend that no demand factor be used in determining the size of circuit to install so that the additional current capacity, thus allowed in the circuit, will give some spare capacity for growth. Refer to Sec. **42** for further discussion on allowance for growth.

The following formulas give the methods of computing the maximum-demand starting and running currents for motor feeders and mains:

$$\begin{pmatrix}\text{Starting}\\ \text{current}\end{pmatrix} = \begin{pmatrix}\text{starting}\\ \text{current}\\ \text{of largest}\\ \text{motor}\end{pmatrix} + \left[\begin{pmatrix}\text{demand}\\ \text{factor}\end{pmatrix} \times \begin{pmatrix}\text{sum of full-}\\ \text{load rated cur-}\\ \text{rents of all the}\\ \text{motors except}\\ \text{the largest}\end{pmatrix}\right] \quad (5)$$

$$\begin{pmatrix}\text{Running}\\ \text{current}\end{pmatrix} = \begin{pmatrix}1.25 \times\\ \text{full-load}\\ \text{current}\\ \text{of larg-}\\ \text{est motor}\end{pmatrix} + \left[\begin{pmatrix}\text{demand}\\ \text{factor}\end{pmatrix} \times \begin{pmatrix}\text{sum of full-}\\ \text{load rated cur-}\\ \text{rents of all}\\ \text{motors except}\\ \text{largest}\end{pmatrix}\right] \quad (6)$$

Where a number of motors of equal horsepower rating are the largest in the group supplied by the circuit, one of these motors should be taken as the largest motor for the calculation of the load on the circuit.

Where two or more motors must be started at the same time, it will generally be necessary to increase the load on the circuit above the values obtained from Eqs. (5) and (6).

Example.—Determine the load on a 220-volt feeder supplying two 10-hp. and two 15-hp. motors. All the motors are three-phase, squirrel-cage induction, normal-starting-current type started at reduced voltage.

Solution.—From Table 9 of Div. 11 the full-load current of a 10-hp., 220-volt, squirrel-cage induction, three-phase motor is 27 amp., and the full-load current of a 15-hp. motor is 40 amp. The starting current of a 15-hp., squirrel-cage induction motor started at reduced voltage from Table 14 of Div. 11 is 200 per cent of the full-load current.

$$\begin{aligned}\text{Maximum-demand starting current} &= (2.00 \times 40) + 40 + (2 \times 27)\\ &= 80 + 40 + 54\\ &= 174 \text{ amp.}\\ \text{Maximum-demand running current} &= (1.25 \times 40) + 40 + (2 \times 27)\\ &= 144 \text{ amp.}\end{aligned}$$

Example.—Determine the load on a 440-volt feeder supplying three 5-hp. motors two 10-hp. motors, and three 15-hp. motors. All the motors are of the low-starting-current, squirrel-cage type, three phase.

Solution.—From Table 9 of Div. 11 the full-load current of a 5-hp., three-phase, low-starting-current, squirrel-cage motor is 7.5 amp.; of a 10-hp. motor, 14 amp.; and of a 15-hp. motor, 20 amp. From Table 5 of Div. 11 the maximum-demand factor is 0.75. Permission has been obtained for the use of this factor.

$$\begin{aligned}\text{Maximum-demand starting current} &= (2.5 \times 20) + 0.75[(3 \times 7.5) + (2 \times 14) + (2 \times 20)]\\ &= 50 + 0.75(22.5 + 28 + 40)\\ &= 118 \text{ amp.}\\ \text{Maximum-demand running current} &= (1.25 \times 20) + 0.75[(3 \times 7.5) + (2 \times 14) + (2 \times 20)]\\ &= 25 + 0.75(22.5 + 28 + 40)\\ &= 93 \text{ amp.}\end{aligned}$$

Example.—Determine the load on a 230-volt, d-c feeder supplying three 3-hp. motors, five 5-hp. motors, and one 20-hp. motor.

Solution.—From Table 6 of Div. 11 the full-load current of a 3-hp., 230-volt, d-c motor is 12.0 amp.; of a 5-hp. motor, 20 amp., and a 20-hp. motor, 74 amp. The starting current of a d-c motor from Table 14 of Div. 11 is 150 per cent of its full-load current. From Table 5 of Div. 11 the maximum-demand factor for nine motors is 0.75. Permission has been obtained for the use of this factor.

$$\begin{aligned}\text{Maximum-demand starting current} &= (1.50 \times 74) + 0.75[(3 \times 12) + (5 \times 20)]\\ &= 111 + 0.75(36.0 + 100)\\ &= 111 + 102 = 213 \text{ amp.}\\ \text{Maximum-demand running current} &= (1.25 \times 74) + 0.75[(3 \times 12.0) + (5 \times 20)]\\ &= 93 + 0.75(36 + 100)\\ &= 93 + (0.75 \times 136)\\ &= 93 + 102 = 195 \text{ amp.}\end{aligned}$$

61. Load on Combined Motor and Lighting Circuits.—In cases where both motors and lamps are fed from the same circuit, proceed as follows in determining the total load of the circuit:

1. Determine the lighting and appliance load.

2. Determine the motor load.

3. Total load is equal to the sum of the lighting and motor loads.

62. General Considerations in Computing Voltage Drop.—In making calculations for the voltage drop in a circuit the future current (Sec. **42**) should be used for lighting and appliance circuits, the maximum running current with allowance for growth (Sec. **42**) for motor feeders or mains, and the full-load current for motor branch circuits.

The resistance employed in the calculations should be the value corresponding to the operating temperature of the conductors. The following rules with respect to the values of operating temperatures to employ in voltage-drop calculations represent good practice for wires loaded between 50 to 100 per cent of their allowable carrying capacity.

1. Use 60°C. for wires insulated with Code or moisture-resistant rubber compounds, synthetic rubberlike compounds, or thermoplastic compounds. Types R, RW, T, and TW wires.

2. Use 70°C. for wires insulated with heat-resistant rubber compound, varnished cambric, paper, thermoplastic and asbestos, slow-burning or weatherproof compounds. Types RH, V, TA, SB, SBW, and WP.

3. Use 100°C. for all wires not included in 1 and 2 above. For wires loaded less than 50 per cent of their allowable carrying capacity the temperature should be reduced from 15 to 20° below the above values. The resistance of copper wire varies somewhat with the method of drawing the wire. As a general rule the voltage drop of a circuit will depend upon several variables, the value of which cannot possibly be determined accurately. It is not practical, therefore, to spend too much time in accurately determining the value of the resistance of the wires. An average value of 98 per cent conductivity for copper wires is generally satisfactory. Copper of 98 per cent conductivity has a resistivity of approximately 10.6 ohms per cir. mil-ft. at 20°C., 11.2 ohms at 30°, 11.6 at 40°, 11.8 at 50°, 12.3 at 60°, and 12.7 at 70°. Tables of resistance of wires are given in Div. 11.

The length of the circuit should be taken as the distance along the circuit from the supply end to the load center. Where a load is distributed along the circuit, the total current does not flow the complete length of the circuit. Therefore, if the actual length of the circuit were used in computing the voltage drop, the drop determined would be greater than the drop that would actually occur. The load center of a circuit is that point in the circuit where, if the load were concentrated at that point, the drop would be the same as the voltage drop to the farthest load in the actual circuit.

63. The load center of a circuit may be determined in the following manner: Multiply each load by its distance from the supply end of the circuit. Add these products for all the loads fed from the circuit and divide this sum by the sum of the individual loads. The result thus obtained is the distance from the supply end of the circuit to the load

center. It is this length that should be employed in computing the voltage drop of the circuit (see solution of example in Fig. 33).

The load center of a group of receivers symmetrically arranged (Fig. 34) and all of the same output will be in the middle of the group. Always take the distance along the circuit as L, Fig. 34.

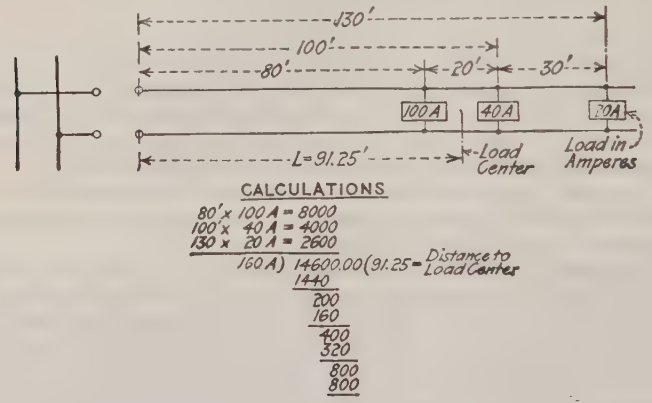


FIG. 33.—Method of computing location of load center.

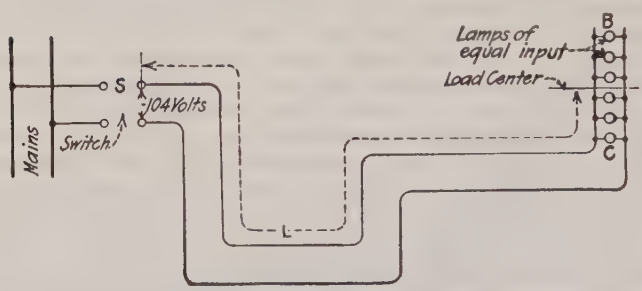


FIG. 34.—Illustrating location of load center.

64. Calculation of Voltage Drop in D-c, Two-wire Circuits by Means o Formula.—The voltage drop may be calculated by means of either Eq (7) or (8), and the size of wire to produce a given voltage drop can b calculated by Eq. (9).

$$V = 2R \times L \times I \qquad (7$$

where V = drop in volts in the circuit; R = resistance of wire in ohms pe foot (values of resistance for copper conductors can be obtained fro Table 46 of Div. 11); I = current in amperes; and L = length one wa of circuit in feet.

$$V = \frac{2K \times L \times I}{\text{cir. mils}} \qquad (8$$

where V = drop in volts in the circuit; K = resistivity of material of conductor in ohms per circular mil foot (values of K for copper conductors can be obtained from Sec. **62**; sufficient accuracy will be obtained for most cases by using the following more approximate values: 12 for circuits loaded between 50 and 100 per cent of their allowable carrying capacity and 11 for circuits loaded less than 50 per cent of their allowable carrying capacity); I = current in amperes; L = length one way of circuit in feet; cir. mils = area of conductor in circular mils.

$$\text{Cir. mils} = \frac{2K \times I \times L}{V} \tag{9}$$

65. Determination of Voltage Drop in D-c, Two-wire Circuits by Means of Chart.—A graph for computing the voltage drop in circuits (Sec. **38** of Div. 11) was originally proposed by R. W. Stovel and N. A. Carle in *The Electric Journal* for June, 1908. It is based on a resistivity of 10.7 ohms per circular-mil foot of copper wire. The chart will, therefore, give satisfactory results for circuits loaded less than 50 per cent of their allowable carrying capacity. For most circuits, which are loaded to between 50 and 100 per cent of their allowable carrying capacity, the voltage drop obtained from the chart should be increased by 10 per cent. The length of the circuit that should be employed in using the chart is the distance from the supply end to the load center. The voltage drop as read from the chart is the total drop in both wires. In order to determine the voltage drop of a circuit from the chart, proceed as follows:

1. Start on the lower left-hand scale with the current for the circuit.
2. Follow this point vertically upward to the diagonal line for the size of wire of the circuit.
3. From this intersection proceed horizontally to the right to the diagonal line representing the length of the circuit one way.
4. At this intersection drop vertically to the voltage-drop scale.
5. The reading on the voltage-drop scale will be the drop in volts in both wires of the circuit for lightly loaded circuits as discussed above.
6. For normally loaded circuits the voltage drop will be equal to 1.1 times the value read from the chart.

Example.—What will be the voltage drop of the motor feeder for the last problem of Sec. **60**, if the length of circuit is 150 ft. and a No. 4/0 Type RH wire is employed?

Solution.—The maximum-demand running current of 195 amp. should be used in determining voltage drop. From Table 48 of Div. 11 a No. 4/0 wire has 211,600 cir. mils and from Table 18A of Div. 11 has a carrying capacity of 230 amp.

Using the formula

$$V = \frac{24 \times I \times L}{\text{cir. mils}} = \frac{24 \times 195 \times 150}{211{,}600} = 3.32 \text{ volts drop}$$

Using the chart: Start at the bottom of the chart on the left-hand side at 195 amp. and follow this point vertically upward until it intersects the diagonal line marked No. 0000. From this intersection proceed horizontally to the right until the diagonal line marked

150 is reached. At this intersection drop vertically downward to the voltage-drop scale, and read 3.0 volts. Since the wire is loaded to more than 50 per cent of its capacity, the voltage drop equals $3.0 \times 1.1 = 3.3$ volts.

66. Determination of Voltage Drop in D-c, Three-wire Circuits.—Either the formulas of Sec. **64** or the chart of Sec. **38**, Div. 11, may be used for determining the voltage drop of d-c, three-wire circuits. In either case the current used should be that of the more heavily loaded outside wire, and the size of conductor that of the outside conductors. The drop thus obtained from either the formula or the chart will be the drop between the outside wires. What is desired is the drop across each receiver or the drop between an outside wire and the neutral wire. The approximate voltage drop to each receiver will be one-half of the value determined from either the formula or the chart. This value will be correct for a balanced load. When the load is unbalanced the current in the neutral wire will cause an additional voltage drop which will not have the same effect on the two sides of the circuit. Since in a well-laid-out system the load will be nearly balanced, the method given is satisfactory for most cases.

Example.—Determine the voltage drop on a three-wire lighting feeder 100 ft. long. The actual load on one side is 147 amp., and on the other side 158 amp. The future load on one side is 170 amp., and on the other side 175 amp. A No. 4/0 Type R wire is used for the outside conductors.

Solution.—The future load on the more heavily loaded side should be used in determining voltage drop. A No. 4/0 Type R wire from Table 48, Div. 11, has 211,600 cir. mils, and from Table 18A, Div. 11, a carrying capacity of 195 amp.

Using the formula

$$V = \frac{24 \times I \times L}{\text{cir. mils}} = \frac{24 \times 175 \times 100}{211{,}600} = 1.98 \text{ volts}$$

Using the chart: Start at the bottom of the chart on the left-hand side at 175 amp. and follow this point vertically upward until it intersects the diagonal line marked No. 0000. From this intersection follow horizontally to the right until the diagonal line marked 100 is reached. At this intersection drop vertically downward to the voltage-drop scale, and read 1.8 volts' drop. The voltage drop will be equal to $1.8 \times 1.1 = 1.98$.

The drop across each receiver is one-half of the drop determined by the formula or chart. The drop across each receiver is, therefore, 0.99 volts determined either from the formula or chart.

67. The voltage drop in a-c circuits is affected by several factors that have no effect in d-c circuits. These factors are (1) power factor of the load, (2) inductance of the circuit, (3) capacity of the circuit, and (4) increased resistance of the circuit to alternating current.

As discussed in Div. 1, when alternating current flows in a circuit, the resistance is increased, owing to skin effect. This increase in resistance for most circuits is so small that it need not be considered. Unless the size of the conductor is greater than 750,000 cir. mils for 25-cycle circuits or 300,000 cir. mils for 60-cycle circuits, skin effect may be neglected, and the resistance of the wire taken the same as for direct current. When

skin effect must be considered in copper conductors, its effect can be allowed for by multiplying the d-c resistance of the wire by the proper factor from Tables 46, 49, or 50 of Div. 11. The a-c resistances for all-steel, copper-steel, and aluminum cable, steel-reinforced, can be determined directly from Tables 51 to 55 in Div. 11.

As discussed in Div. 1 the phenomenon of inductance causes a voltage to be induced in an a-c circuit which opposes the flow of current in the circuit. Inductance, therefore, offers opposition to the flow of alternating current in a circuit. This opposition is called the inductive reactance of the circuit and is represented by the symbol X_L. The value of the inductive reactance of a circuit depends upon the size of the wire, the distance between the wires of the circuit, the frequency of the current flowing in the circuit, the material of the conductor, and the presence of any magnetic material in proximity to the circuit. The voltage drop, due to inductance, produced in a circuit is equal to the current times the inductive reactance. For small-sized conductors the effect of inductance is so small that it can be neglected (see Sec. **39** of Div. 11).

The two conductors of any circuit with the insulation between them produce a condenser. They therefore introduce capacity into the circuit. The effect of capacity in an a-c circuit is to offer opposition to the flow of current. This opposition is called capacity reactance and is denoted by the symbol X_c. The voltage drop in a circuit due to capacity is equal to the current times the capacity reactance. The effect of capacity upon the voltage drop of the circuit is so small except for high-voltage, long-distance transmission lines that it is neglected.

The total voltage drop in an a-c circuit due to the resistance and reactance is affected by the power factor of the load connected to the circuit.

68. Summary of Factors That Must Be Considered in Calculating Drop for A-c Circuits.—Skin effect can usually be neglected unless the size of wires is greater than 300,000 cir. mils for 60-cycle circuits or 750,000 cir. mils for 25-cycle circuits.

The effect of capacity can be neglected except for long-distance transmission lines.

The effect of inductance can be neglected unless the size of wire exceeds the values given in Table 39 of Div. 11.

69. Line or circuit reactance can be reduced in three ways. One of these is to diminish the distance between wires. The extent to which this can be carried is limited, in the case of a pole line, to the least distance at which the wires are safe from swinging together in the middle of a span. In inside wiring (knob or cleat work), it is limited by the separation distances required by the Underwriters. In conduit work, nothing can be done about reducing the distance between wires. Another way of reducing the reactance is by increasing the size of the conductors, but it is not possible to secure much reduction by this method unless the size is increased an excessive amount. The third way of reducing reactance is to

divide the load into a greater number of circuits. Voltage drop in lines due to inductive reactance is best diminished (Mershon) by subdividing the copper or by bringing the conductors closer together. It is little affected by changing the size of conductor.

70. Determining Power Factors of Feeders or Mains.—Although the values of power factors obtained the following method are approximate, they are accurate enough for most circuit calculations. To determine the power factor of a circuit supplying several motors proceed as follows:

1. Multiply the horsepower of each motor by its power factor at 75 per cent of rated load.
2. Add these products for all the motors fed from the line.
3. The approximate power factor of the circuit will equal the sum obtained in (2) divided by the total horsepower connected to the circuit.

Approximate power factors of different types of loads are given in Table 41 of Div. 11.

Example.—Determine the power factor for a feeder supplying two 5-hp. motors, five 10-hp. motors, and one 50-hp. motor.

Solution.

Hp. of motor	×	power factor (From Table 41, Div. 11)	=	product of hp. and p.f.
5	×	0.83	=	4.15
5	×	0.83	=	4.15
10	×	0.86	=	8.6
10	×	0.86	=	8.6
10	×	0.86	=	8.6
10	×	0.86	=	8.6
10	×	0.86	=	8.6
50	×	0.89	=	44.5
110 total connected hp.				95.8

$$\text{Approximate power factor of circuit} = \frac{\text{sum of products of hp. and p.f.}}{\text{total connected hp.}}$$

$$= \frac{95.8}{110} = 87.1$$

71. Calculation of Voltage Drop in Two-wire, Single-phase Circuits When Effect of Inductance Can Be Neglected.—These circuits may be calculated in the same way as d-c circuits, by means of either the formulas of Sec. **64** or the chart of Sec. **38** of Div. 11.

72. Calculation of Voltage Drop in Three-wire, Single-phase Circuits When Effect of Inductance Can Be Neglected.—Circuits of this type may be calculated in exactly the same manner as three-wire, d-c circuits (see Sec. **66**).

73. Calculation of Voltage Drop in Four-wire, Two-phase Circuits When Effect of Inductance Can Be Neglected.—A four-wire, two-phase circuit may be considered as two separate single-phase circuits, and the voltage drop computed in the same manner as given for two-wire, d-c circuits in either Sec. **64** or Sec. **65**.

74. Calculation of Voltage Drop in Three-wire, Two-phase Circuits When Effect of Inductance Can Be Neglected.—The voltage drop in the common wire of three-wire, two-phase systems somewhat unbalances the voltages of the two phases, and, therefore, the voltage drop of the two phases is not the same. An exact method of the calculation of the voltage drop of these circuits is too complicated for the scope of this book. The following method will give the approximate voltage drop on the phase having the greater voltage drop. It is accurate enough for most interior-wiring calculations. Proceed as follows:

1. Determine the voltage drop in one outside wire. It will be equal to one-half of the voltage drop determined by means of either the formulas of Sec. **64** or the chart of Sec. **38** in Div. 11.

2. Determine the voltage drop in the common wire. This will be equal to one-half of the voltage drop determined by means of either the formulas of Sec. **64** or the chart of Sec. **38** in Div. 11, the size of wire and current for the common wire being used.

3. The total voltage drop is taken as equal to the drop in one outside wire plus 0.8 times the voltage drop in the common wire.

Example.—Determine the voltage drop of a three-wire, two-phase, 60-cycle lighting feeder which is 200 ft. long and installed in conduit. The current in each outside wire is 130 amp. A No. 2/0 wire is used for the outside wires, and a No. 4/0 for the common wire. All wires are Type R.

Solution.—Since the largest wire used is No. 4/0 from Table 39 of Div. 11 the effect of inductance can be neglected. From Table 48 of Div. 11 a No. 2/0 wire has 133,100 cir. mils, and a No. 4/0 wire 211,600 cir. mils. From Table 18A of Div. 11 all wires are loaded to more than 50 per cent of their carrying capacity.

$$\text{Drop in two outside wires} = \frac{24 \times I \times L}{\text{cir. mils}} = \frac{24 \times 130 \times 200}{133{,}100} = 4.7 \text{ volts}$$

$$\text{Drop in one outside wire} = \frac{4.7}{2} = 2.35 \text{ volts}$$

$$\text{Current in common wire} = 1.41 \times 130 = 183.5 \text{ amp.}$$

$$\text{Drop in common wire} = \frac{24 \times I \times L}{2 \times \text{cir. mils}} = \frac{24 \times 183.5 \times 200}{2 \times 211{,}600} = 2.08 \text{ volts}$$

$$\text{Total voltage drop} = 2.35 + (0.8 \times 2.08) = 2.35 + 1.66$$
$$= 4.01 \text{ volts drop}$$

75. Calculation of Voltage Drop in Five-wire, Two-phase Circuits When Effect of Inductance Can Be Neglected.—In a well-laid-out system the load will be very nearly balanced under normal conditions. Therefore, there would be practically no current in the neutral wire. For lighting loads supplied by this system the lamps are connected between the neutral wire and the respective outside wires. The drop to any lamp therefore would be equal to the drop in one outside wire. The drop in one outside wire will be equal to one-half of the drop determined by either the formulas of Sec. **64** or the chart of Sec. **38** of Div. 11. The drop to motors fed by this system would be equal to the drop in two outside wires and, therefore, to the drop determined by either the formula or the chart.

76. Calculation of Voltage Drop in Three-wire, Three-phase Circuits, When Effect of Inductance Can Be Neglected.—The voltage drop in these circuits will be equal to 0.866 times the voltage drop of a two-wire, d-c circuit carrying the same current as the three-phase circuit. This drop may be determined from either the formulas of Sec. **64** or the chart of Sec. **38** of Div. 11.

Example.—Determine the voltage drop of a three-wire, three-phase, 60-cycle motor feeder which is 150 ft. long. Three No. 2 Type R wires are installed in conduit. The current is 85 amp.

Solution.—Since the size of wire is No. 2, from Table 39 of Div. 11 the effect of inductance can be neglected. From Table 48 of Div. 11 a No. 2 wire has 66,370 cir. mils, and from Table 18A of Div. 11 a carrying capacity of 95 amp.

The drop in a two-wire, d-c circuit carrying 85 amp. over a No. 2 wire $= \frac{24 \times I \times L}{\text{cir. mils}}$

$$= \frac{24 \times 85 \times 150}{66{,}370} = 4.61 \text{ volts}$$

Therefore, drop of the three-phase system $= 0.866 \times 4.61$
$= 4.0$ volts

77. Calculation of Voltage Drop in Four-wire, Three-phase Circuits When Effect of Inductance Can Be Neglected.—In a well-laid-out system the load will be very nearly balanced under normal load conditions. Therefore, there will be practically no current in the neutral wire. For lighting loads supplied by this system the lamps are connected between the neutral wire and the respective outside wires. The drop to any lamp, therefore, is equal to the drop in one outside wire. The drop in one outside wire will be equal to one-half of the drop determined by either the formulas of Sec. **64** or the chart of Sec. **38** of Div. 11. The drop to motors fed by this system is the drop between any two outside wires. This drop is equal to 0.866 times the voltage drop of a two-wire, d-c system carrying the same current as the three-phase system. (Use either the formulas of Sec. **64** or the chart of Sec. **38** of Div. 11 for determining the d-c drop.)

78. Calculation of Circuits When Effect of Inductance Cannot Be Neglected.—Two methods are given in the following paragraphs for calculating the voltage drop of circuits when the effect of inductance is so great that it cannot be neglected (see Sec. **39** of Div. 11 for rules indicating when inductance must be considered). In one of these methods the voltage drop in the actual a-c circuit is calculated by multiplying the drop of a d-c circuit by a factor called the drop factor. This drop factor is the ratio between the actual drop and the drop that would occur if there were no inductance. The drop factor is affected by the size of wire, spacing of the wires of the circuit, the frequency of the current, and the power factor of the load. Values of drop factors for various conditions in which concentric stranded copper conductors are used are given in Table 44 of Div. 11.

The other method given for computing the voltage drop of circuits, when the effect of inductance cannot be neglected, makes use of a diagram called the Mershon diagram (Fig. 35).

Under ordinary conditions of use both of these methods will give results of about the same degree of accuracy. If the Mershon diagram is used carefully, it will give the more accurate results of the two. But, since in the calculation of most circuits several factors are based on assumption, the greater accuracy of the Mershon diagram is of questionable value.

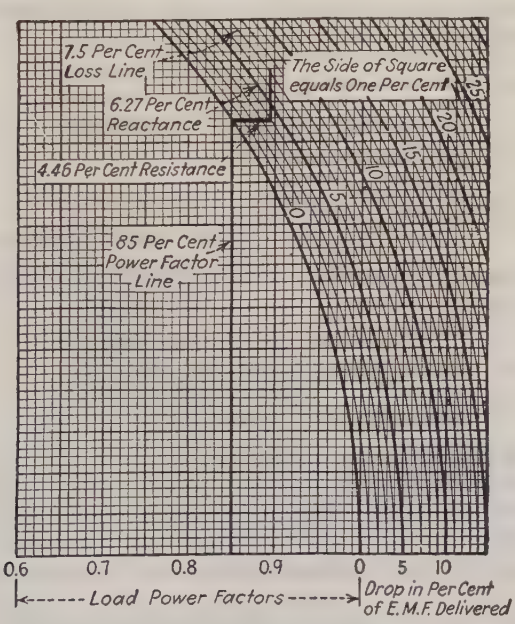


FIG. 35.—Illustrating the application of the Mershon diagram for computing a single-phase circuit. The side of each small square equals 1 per cent; percentage resistance is measured horizontally and percentage reactance vertically.

The drop-factor method is certainly accurate enough for the calculation of all interior-wiring circuits, and the writer believes that it is the more easily applied method of the two. For circuits employing some type of conductor material or construction other than stranded copper, the Mershon diagram will have to be used, since no data are given for drop factors for conductors of other types.

79. Drop-factor Method of Calculating Voltage Drop When Effect of Inductance Cannot Be Neglected.—Proceed as follows:

1. Determine from either Secs. **64** or **65** the voltage drop of a two-wire, d-c system carrying the same current, and using the same size wire.

2. Determine the ratio of reactance to resistance for the size of wire, spacing of wires, and frequency of the circuit considered (see Table 42 or 43 of Div. 11).

3. Determine power factor of circuit (see Sec. **70** and Table 41 of Div. 11).

4. Determine the drop factor for the circuit corresponding to the determined ratio of reactance to resistance and power factor of the circuit from Table 44 of Div. 11.

5. The voltage drop of the circuit then is determined as follows, depending upon the electric system:

For two-wire, single-phase systems:

$$\text{Voltage drop} = \text{drop factor} \times \text{d-c voltage drop} \tag{10}$$

For three-wire, single-phase systems:

$$\text{Voltage drop between outside wires} = \text{drop factor} \times \text{d-c voltage drop} \tag{11}$$

$$\text{Voltage drop between outside wire and neutral (lamps)} = \tfrac{1}{2}\ (\text{drop factor} \times \text{d-c voltage drop}) \tag{12}$$

For four-wire, two-phase systems, each phase is considered as a separate two-wire, single-phase system.

$$\text{Voltage drop} = \text{drop factor} \times \text{d-c voltage drop} \tag{13}$$

For three-wire system tapped from four-wire three-phase system:

$$\text{Voltage drop} = 0.75\ (\text{drop factor} \times \text{d-c voltage drop}) \tag{14}$$

For three-wire, two-phase systems two d-c drops must first be determined: one for a two-wire, d-c circuit carrying the same current and with the same size wire as the outside conductors of the two-phase system, and the other for a two-wire, d-c circuit carrying the same current and with the same size wire as the common wire of the two-phase system. Then

$$\text{Voltage drop of two-phase, three-wire system} = \left[\frac{\left(\begin{matrix}\text{drop}\\ \text{factor}\end{matrix}\right) \times \left(\begin{matrix}\text{d-c voltage drop for}\\ \text{current and size of}\\ \text{outside wire}\end{matrix}\right)}{2}\right] + \left[0.8 \times \frac{\left(\begin{matrix}\text{drop}\\ \text{factor}\end{matrix}\right) \times \left(\begin{matrix}\text{d-c voltage drop for current}\\ \text{and size of wire of common}\\ \text{wire}\end{matrix}\right)}{2}\right] \tag{15}$$

For five-wire, two-phase systems:

$$\text{Voltage drop for lamps} = \frac{\text{drop factor} \times \text{d-c voltage drop}}{2} \tag{16}$$

$$\text{Voltage drop for motors} = \text{drop factor} \times \text{d-c voltage drop} \tag{17}$$

For three-wire, three-phase systems:

$$\text{Voltage drop} = 0.866 \times \text{drop factor} \times \text{d-c voltage drop} \tag{18}$$

For four-wire, three-phase systems:

$$\text{Voltage drop for lamps} = \frac{\text{drop factor} \times \text{d-c voltage drop}}{2} \tag{19}$$

$$\text{Voltage drop for motors} = 0.866 \times \text{drop factor} \times \text{d-c voltage drop} \tag{20}$$

Example.—Determine the voltage drop of a two-wire, single-phase, 60-cycle motor circuit carrying a current of 250 amp. for a distance of 150 ft. A 300,000-cir. mil, Type RH wire is used, installed in conduit. The power factor of the circuit is 80 per cent.

Solution.—From Table 39 of Div. 11, since the size of wire is 300,000 cir. mils, the effect of inductance cannot be neglected. The carrying capacity from Table 18A of Div. 11 is 285 amp.

The drop of a two-wire, d-c circuit carrying 250 amp. over a 300,000-cir. mil wire for 150 ft. $= \frac{24 \times I \times L}{\text{cir. mils}} = \frac{24 \times 250 \times 150}{300{,}000} = 3.0$ volts.

From Table 42 of Div. 11 the ratio of reactance to resistance for a 300,000-cir. mil wire installed in conduit on a 60-cycle system is 1.01.

From Table 44 of Div. 11 the drop factor for a ratio of reactance to resistance of 1.01, and a power factor of 80 per cent is 1.40.

Voltage drop of the actual circuit = drop factor $\times$ d-c drop $= 1.40 \times 3.0 = 4.2$ volts.

Example.—Determine the voltage drop of the above circuit, if it were a three-wire, single-phase one.

Solution.—The voltage drop between outside wires would be equal to the drop factor times the drop of a two-wire, d-c system carrying the same current $= 1.40 \times 3.0 = 4.2$ volts.

Voltage drop across lamps if connected to the circuit would be the drop between an outside wire and the neutral $= \frac{1.40 \times 3.0}{2} = 2.1$ volts.

Example.—Determine the voltage drop of the above circuit if it were three-wire tapped from a four-wire three-phase system.

Solution.—Voltage drop across lamps $= 0.75 \times 1.4 \times 3.0 = 3.15$ volts.

Example.—Determine the voltage drop of the preceding circuit, if it were a four-wire, two-phase system.

Solution.—Voltage drop = drop factor $\times$ d-c drop
$= 1.40 \times 3.0 = 4.2$ volts

Example.—Determine the voltage drop of the preceding circuit, if it were a three-wire, two-phase one. The 250 amp. is the current in the outside wires.

Solution.—The current in the common wire $= 1.41 \times 250 = 352$ amp. Use a 500,000-cir. mil wire for the common.

The voltage drop for a two-wire, d-c system carrying 250 amp. over a 300,000-cir. mil wire for 150 ft. $= \frac{24 \times I \times L}{300{,}000} = \frac{24 \times 250 \times 150}{300{,}000} = 3.0$ volts.

The voltage drop for a two-wire, d-c circuit carrying 352 amp. for 150 ft. over a 500,000-cir. mil wire $= \frac{24 \times I \times L}{500{,}000} = \frac{24 \times 352 \times 150}{500{,}000} = 2.54$ volts.

From preceding problems the drop factor for the outside conductors = 1.40.

From Table 42 of Div. 11 the ratio of reactance to resistance for a 500,000-cir. mil wire installed in conduit on a 60-cycle system is 1.75.

From Table 44 of Div. 11 the drop factor for a ratio of reactance to resistance of 1.75 and a power factor of 80 per cent is 1.88.

$$\text{Voltage drop of actual circuit} = \frac{\left(\begin{matrix}\text{drop}\\ \text{factor}\end{matrix}\right) \times \left(\begin{matrix}\text{d-c voltage}\\ \text{drop for current}\\ \text{and size of wire}\\ \text{of outside wires}\end{matrix}\right)}{2} + 0.8 \times \frac{\left(\begin{matrix}\text{drop}\\ \text{factor}\end{matrix}\right) \times \left(\begin{matrix}\text{d-c voltage drop}\\ \text{for current and}\\ \text{size of wire of}\\ \text{common wire}\end{matrix}\right)}{2}$$

$$= \frac{1.40 \times 3.0}{2} + \frac{0.8 \times 1.88 \times 2.54}{2} = 2.1 + 1.91$$

$$= 4.01 \text{ volts}$$

Example.—Determine the voltage drop of the preceding circuit, if it were a five-wire, two-phase system.

Solution.—Voltage drop for motors = drop factor × d-c voltage drop
$= 1.40 \times 3.0 = 4.2$ volts

If there were any lamps connected to the circuit, the voltage drop across each lamp

$$= \frac{\text{drop factor} \times \text{d-c voltage drop}}{2}$$

$$= \frac{1.40 \times 3.0}{2} = 2.1 \text{ volts}$$

Example.—Determine the voltage drop of the preceding circuit, if it were a three-wire, three-phase system.

Solution.—Voltage drop = 0.866 × drop factor × d-c voltage drop
$= 0.866 \times 1.40 \times 3.0 = 3.64$ volts

Example.—Determine the voltage drop of the preceding circuit, if it were a four-wire, three-phase system.

Solution.—Voltage drop for motors = 0.866 × drop factor × d-c voltage drop
$= 0.866 \times 1.40 \times 3.0 = 3.64$ volts

If there were any lamps connected to the circuit the voltage drop across each lamp

$$= \frac{\text{drop factor} \times \text{d-c voltage drop}}{2}$$

$$= \frac{1.40 \times 3.0}{2} = 2.1 \text{ volts}$$

80. Calculation of Voltage Drop of Two-wire, Single-phase Circuits by Mershon Diagram When Effect of Inductance Cannot Be Neglected.—Proceed as follows:

1. Determine the a-c resistance of the total length of wire. This will be equal to the resistance per foot of wire of the size and material employed multiplied by 2 times the length of circuit one way in feet. Care should be exercised in taking values of resistance from the tables to observe in what units the resistance is given. Some values are given in ohms per 1,000 ft. and others in ohms per mile. For copper conductors use Table 46 of Div. 11. The a-c resistance will be equal to the d-c resistance at the working temperature of the wire times the skin-effect correction factor. For all-steel conductors use Table 51 of Div. 11; for copper-steel, Table 52 of Div. 11; and for aluminum cable, steel-reinforced, Table 54 of Div. 11. These three tables give the values of a-c resistance directly. In using Table 54, it is first necessary to determine the amperes per square inch for the cable employed. The area in square inches will be equal to the area in circular mils times 0.7854 divided by 1,000,000.

2. Determine the resistance volts drop. This will be equal to the resistance of the total length of wire as determined in step 1 multiplied by the current.

3. Determine the inductive reactance of the total length of wire. This will be equal to the reactance per foot of wire for the size, material, and spacing of wires multiplied by 2 times the length of circuit one way in feet. Care should be exercised in taking values of reactance from the tables to observe in what units the reactance is given; some values are given in ohms per 1,000 ft. and others in ohms per mile. For copper conductors use Secs. **56** to **60** of Div. 11. If a cable has a metallic armor of magnetic material or other magnetic binder, the correction factors of Table 46 of Div. 11 should be applied to the reactance values taken from Secs. **56** to **60**. For all-steel conductors use Table 61 of Div. 11; for copper-steel, Table 62 of Div. 11; for copperweld, Table 63 of Div. 11; and for aluminum cable, steel-reinforced, Tables 64 or 65 of Div 11. In using Tables 64 or 65 the amperes per square inch must be determined in order to select the proper column.

4. Determine the reactance volts drop. This will be equal to the reactance of the total length of wire as determined in step 3 multiplied by the current.

5. Find what percentage the resistance volts drop is of the voltage delivered at the end of the line.

6. Find what percentage the reactance volts drop is of the voltage delivered at the end of the line.

7. Determine the power factor of the circuit (see Sec. **70** and Table 41 of Div. 11).

8. On the Mershon diagram (Fig. 35) start at the point where the vertical line corresponding to the power factor of the circuit intersects the smallest circle.

9. From this point lay off horizontally to the right the percentage of resistance volts drop. From the point thus obtained lay off vertically upward the percentage of reactance volts drop.

10. The circle upon which the last point obtained falls will give the voltage drop in percentage of the voltage at the end of the line.

Example.—Determine the voltage drop of a 60-cycle, 110-volt circuit carrying 200 amp. a distance of 222 ft. The power factor of the circuit is 85 per cent. The wires are No. 4/0, Type R, spaced 6 in. apart.

Solution.—From Sec. 62 the temperature of the conductors would be taken as 50°C., since Type R wire is used and it will be loaded to more than 50 per cent of its allowable carrying capacity. From Table 46 of Div. 11, the skin-effect correction factor is 1.00, so that the resistance per 1,000 ft. will be the same as for direct current at 50°C. From the table this is 0.0552.

$$\text{Resistance volts drop} = \frac{0.0552}{1{,}000} \times 2 \times 222 \times 200 = 4.91 \text{ volts}$$

$$\text{Percentage resistance volts drop} = \frac{4.91}{110} \times 100 = 4.46 \text{ per cent}$$

From the curves of Sec. **57** of Div. 11 a circuit of No. 4/0 wire, 1,000 ft. long on a 60-cycle system with the wires spaced 6 in. apart, has a reactance of 0.0775.

$$\text{Reactance volts drop} = \frac{0.0775}{1{,}000} \times 2 \times 222 \times 200 = 6.89 \text{ volts}$$

$$\text{Percentage reactance volts drop} = \frac{6.89}{110} \times 100 = 6.27 \text{ per cent}$$

Applying the Mershon diagram to this problem as shown in Fig. 35 the total drop in percentage of the 110 volts at the end of the line is 7.5 per cent.

$$\text{Total volts drop} = \frac{110 \times 7.5}{100} = 8.25 \text{ volts}$$

81. Calculation of Voltage Drop by Mershon Diagram for Any Circuit When Effect of Inductance Cannot Be Neglected.—First, determine as outlined in Sec. **80**, the voltage drop for a two-wire, single-phase circuit of the same size wire carrying the same current as the actual circuit. Then, proceed as follows for the particular system involved:

Three-wire, single-phase:

$$\text{Voltage drop between outside wires} = \text{drop as read from diagram} \quad (21)$$

$$\text{Voltage drop between outside wire and neutral (lamps)} = \frac{\text{drop as read from diagram}}{2} \quad (22)$$

Three-wire, tapped from three phase four-wire:

$$\text{Voltage drop between outside wire and neutral (lamps)} = 0.75 \text{ (drop as read from diagram)} \quad (23)$$

Four-wire, two-phase systems: Each phase is considered as a separate two-wire, single-phase system.

Three-wire, two-phase systems: Determine two drops from the diagram, one for a circuit with size of wire and current of outside wires of two-phase system, and the other for a circuit with size of wire and current of common wire.

Then

$$\text{Voltage drop} = \left(\frac{\text{drop for circuit with size of wire and current of outside wires}}{2}\right) + 0.8 \times \left(\frac{\text{drop for circuit with size of wire and current of common wire}}{2}\right) \quad (24)$$

Five-wire, two-phase systems:

$$\text{Voltage drop for lamps} = \frac{\text{drop from diagram}}{2} \quad (25)$$

$$\text{Voltage drop for motors} = \text{drop as read from diagram} \quad (26)$$

Three-wire, three-phase systems:

$$\text{Voltage drop} = 0.866 \times \text{drop as read from diagram} \quad (27)$$

Four-wire, three-phase systems:

$$\text{Voltage drop for lamps} = \frac{\text{drop from diagram}}{2} \quad (28)$$

Voltage drop for motor = 0.866 × drop as read from diagram (29)

Example.—Determine the voltage drop for the circuit of the example in Sec. **80** for the different systems.

Solution.—Referring to the problem in Sec. **80,** the voltage drop of the circuit for a two-wire, single-phase system is 8.25 volts.

For a three-wire, single-phase system:

$$\text{Voltage drop for motors} = \text{drop as read from diagram} = 8.25 \text{ volts}$$

$$\text{Voltage drop for lamps} = \frac{\text{drop as read from diagram}}{2} = \frac{8.25}{2} = 4.13$$

For a four-wire, two-phase system:

$$\text{Voltage drop} = \text{drop as read from diagram} = 8.25 \text{ volts}$$

For a three-wire, two-phase system:

Use must be made of the Mershon diagram to determine another voltage drop. The drop obtained in Sec. **80** is for a two-wire, single-phase circuit carrying the same current as the outside wires of the three-wire, two-phase circuit, and with the same size wire as the outside wires. Another voltage drop for a two-wire, single-phase circuit carrying the same current as the common wire of the three-wire, two-phase circuit, and with the size of wire of the common, must be determined.

$$\text{Current in common wire} = 1.41 \times 200 = 282 \text{ amp.}$$

Assume that a 400,000-cir. mil wire is used for common wire (as large a size would not be required by carrying capacity).

From Table 46 of Div. 11 a circuit of 400,000-cir. mil wire, 1,000 ft. long on a 60-cycle system, will have a resistance of 0.0292 ohms per 1,000 ft. if operated at 50°C.

$$\text{Resistance volts drop} = \frac{0.0292}{1{,}000} \times 2 \times 222 \times 282 = 3.66 \text{ volts}$$

$$\text{Percentage resistance volts drop} = \frac{3.66}{110} \times 100 = 3.32 \text{ per cent}$$

From the curves of Sec. **57** of Div. 11 a circuit of 400,000-cir. mil wire, 1,000 ft. long on a 60-cycle system, with the wires spaced 6 in. apart, will have a reactance of 0.071 ohms per 1,000 ft.

$$\text{Reactance volts drop} = \frac{0.071}{1{,}000} \times 2 \times 222 \times 282 = 8.88 \text{ volts}$$

$$\text{Percentage reactance volts drop} = \frac{8.88}{110} \times 100 = 8.07 \text{ per cent}$$

If the Mershon diagram is applied, a two-wire, single-phase circuit of 85 per cent p.f. carrying 282 amp. over 400,000-cir. mil wires spaced 6 in. apart will give a 7.3 per cent volts drop, or $\frac{7.3 \times 110}{100} = 8.03$ volts

$$\text{Voltage drop for three-wire, two phase circuit} = \frac{8.25}{2} + \left(0.8 \times \frac{8.03}{2}\right) = 4.13 + 3.21 = 7.34$$

For a five-wire, two-phase system:

$$\text{Voltage drop for lamps} = \frac{\text{drop from diagram}}{2} = \frac{8.25}{2} = 4.13$$

$$\text{Voltage drop for motors} = \text{drop as read from diagram} = 8.25 \text{ volts}$$

For a three-wire, three-phase system:

$$\text{Voltage drop} = 0.866 \times \text{drop as read from diagram} = 0.866 \times 8.25 = 7.15 \text{ volts}$$

For a four-wire, three-phase system:

$$\text{Voltage drop for lamps} = \frac{\text{drop from diagram}}{2} = \frac{8.25}{2} = 4.13 \text{ volts}$$

$$\text{Voltage drop for motors} = 0.866 \times \text{drop as read from diagram} = 0.866 \times 8.25 = 7.15 \text{ volts}$$

82. How to Proceed in Determining the Proper Size of Wire for a Circuit.

1. Determine the ampere load on the circuit.

For branch lighting and appliance circuits refer to Secs. **42** to **44.**

For two-wire, d-c or single-phase a-c lighting and appliance mains or feeders refer to Secs. **46, 50,** and **51.**

For three-wire, d-c or single-phase, a-c lighting and appliance mains or feeders refer to Secs. **47, 50,** and **52.**

For four-wire, two-phase lighting and appliance mains or feeders refer to Secs. **50** and **53.**

For three-wire, two-phase lighting and appliance mains or feeders refer to Secs. **48, 50,** and **54.**

For five-wire, two-phase lighting and appliance mains or feeders refer to Secs. **50** and **55.**

For four-wire, three-phase lighting and appliance mains or feeders refer to Secs. **49, 50,** and **56.**

For circuits supplying electric ranges refer to Secs. **45** and **51.**

For branch motor circuit refer to Sec. **59.**

For motor feeders or mains refer to Sec. **60.**

2. For branch lighting or applicance circuits refer to Div. 9 and determine if outlets and equipment supplied by circuit meet the National Electrical Code requirements.

3. For lighting feeders or mains determine the minimum allowable load (refer to Sec. **58**).

4. Select from Secs. **15** to **20** of Div. 11 the size of wire that will carry safely the current with the type of insulation employed on the wires (see also Sec. **37** and **37**A).

For ordinary branch lighting circuits, although No. 14 wire will safely carry the current, it is best not to use smaller than No. 12 wire. If the length of the branch lighting circuit to the load center is over 50 ft., wire at least as large as No. 10 should be used.

A branch circuit supplying an electric range of $8\frac{3}{4}$ kw. or more rating must not be smaller than No. 8 except for the neutral conductor, which must not be smaller than No. 10.

For lighting feeders or mains use the estimated future load current unless it is less than the minimum allowable load, when the minimum allowable load should be used.

For continuous-duty branch motor circuits use 125 per cent of the full-load rated current of the motor.

For branch motor circuits supplying short-time-duty motors, use the proper percentage of the rated current as given in Table 10 of Div. 11.

For motor feeders or main use the maximum-demand running current with allowance for growth.

For three-wire, d-c or single-phase systems the neutral wire should have a carrying capacity equal to that of the current in the outside wires, if the current in the outside wires is 200 amp. or less. If the current in the outside wires is greater than 200 amp., the common wire should have a carrying capacity equal to 200 plus 0.7 of the current in the outside wires in excess of 200 amp.

For three-wire, two-phase systems the common wire should have a carrying capacity equal to 1.41 times the current in the outside wires.

For five-wire, two-phase systems the neutral should have a carrying capacity equal to 1.41 times the current in the outside wires, if the current in the outside wires is 200 amp. or less. If the current in the outside wires is greater than 200 amp., the neutral should have a carrying capacity equal to 1.41 times 200 plus the current in the outside wires in excess of 200 amp.

For four-wire, three-phase systems the neutral wire should have a carrying capacity equal to the current in the outside wires, if the current in the outside wires is 200 amp. or less. If the current in the outside wires is greater than 200 amp., the neutral should have a carrying capacity equal to 200 plus 0.7 of the current in the outside wires in excess of 200 amp.

The neutral conductor of a three-wire circuit supplying a single range with a maximum demand of $8\frac{3}{4}$ kw. or more is allowed to have a carrying capacity of only 70 per cent of the outside wires, provided that the neutral is not smaller than No. 10.

5. Determine if the size of wire required according to carrying capacity is sufficient for mechanical strength (refer to Sec. **38**).

Be sure that the size of wire required according to carrying capacity is not too large for satisfactory installation (refer to Sec. **39**).

6. Find the distance to the load center of the circuit (refer to Sec. **63**).

7. Decide what voltage drop is allowable in the circuit (refer to Sec. **41** and Table **37** of Div. 11).

8. Determine what will be the voltage drop in the circuit using the size of wire required according to carrying capacity.

If the circuit is an a-c one, before calculating the voltage drop, determine from Sec. **68** and Sec. **39** of Div. 11 whether or not the effects of inductance and skin effect can be neglected.

For branch lighting circuits use the future-load current, unless the maximum allowable load for the type of branch circuit as given in Div. 9 is less than this value. In that case, use the maximum allowable load.

For lighting feeders or mains use the future-load current, unless it is smaller than the minimum allowable load, when the minimum allowable load should be used.

For branch motor circuits use the full-load current of the motor.

For motor feeders or mains use the maximum-demand running current with proper allowance for growth.

For the length of the circuit use the distance from the source of supply to the load center, measured along the circuit.

For method of calculating voltage drop refer to the following sections.

Direct-current, two-wire	Sec. **64** or **65**
Direct-current, three-wire	Sec. **66**
Alternating-current when inductance can be neglected:	
Single-phase, two-wire	Sec. **71**
Single-phase, three-wire	Sec. **72**
Two-phase, four-wire	Sec. **73**
Two-phase, three-wire	Sec. **74**
Two-phase, five-wire	Sec. **75**
Three-phase, three-wire	Sec. **76**
Three-phase, four-wire	Sec. **77**
Alternating-current when the effect of inductance cannot be neglected	Sec. **79** or Secs. **80** and **81**

9. If the voltage drop determined in step 8 is greater than the allowable amount, take the next larger conductor and determine the voltage drop it will give. Proceed in this way, until the conductors are large enough to keep the voltage drop within the required amount. For a-c circuits, this would sometimes require too great an increase in the size of the conductors. In such cases it is best to replan the system so as to divide the load among a greater number of circuits. For systems employing a common or neutral wire, when the size of wire must be increased in order to keep the voltage drop within the allowable amount, it is best to increase the size of the neutral in the same proportion as the outside wires are increased.

Example.—Determine the proper size of wire to use for a two-wire, single-phase, 60-cycle, 115-volt branch lighting circuit supplying six 150-watt lamps. The length of the circuit to the load center is 50 ft. The wires are to be installed in conduit and have rubber insulation.

Solution.

$$\text{Actual connected load} = \frac{6 \times 150}{115} = 7.8 \text{ amp.}$$

$$\text{Future load (Sec. 43)} = \frac{6 \times 200}{115} = 10.5 \text{ amp.}$$

The future load of 10.5 amp. will be used in selecting the size of wire according to both carrying capacity and voltage drop.

From Sec. **82** (item 4) at least a No. 14 wire is required by the code but it is best to use not smaller than No. 12 wire.

From Table 37 of Div. 11 a voltage drop of 2.3 volts would be allowable.

Determine the voltage drop (Secs. **64** or **65**) for a No. 12 wire carrying 10.5 amp. 50 ft.

$$\text{Voltage drop with No. 12 wire} = \frac{24 \times 10.5 \times 50}{6{,}530} = 1.93 \text{ volts}$$

Since this drop is less than the allowable amount, two No. 12 wires should be used.

Example.—A two-wire, single-phase, 60-cycle, 115-volt, branch lighting circuit supplies nine 150-watt lamps. The length of the circuit to the load center is 100 ft. The wires are to be installed in conduit and to be rubber insulated. Determine the proper size of wire to use.

Solution.—Actual connected load $= \frac{9 \times 150}{115} = 11.7$ amp.

$$\text{Future load} = \frac{9 \times 200}{115} = 15.6 \text{ amp.}$$

From Div. 9 the maximum allowable load on such a branch circuit is 15 amp. Since the future load is greater than this, the maximum allowable load of 15 amp. will be used in selecting the size of wire according to both carrying capacity and voltage drop.

From Sec. **82** (item 4) at least a No. 14 wire is required, but it will be best, however, to use not smaller than No. 10 wire when the circuit is over 100 ft. long.

From Table 37 of Div. 11 a voltage drop of 2.3 volts would be allowable.

From Table 39 of Div. 11 the effect of inductance can be neglected for a lighting circuit using No. 10 wire on a 60-cycle system.

$$\text{Voltage drop with No. 10 wire} = \frac{24 \times 15 \times 100}{10{,}380} = 3.47 \text{ volts}$$

Since this voltage drop is greater than the allowable amount, take the next larger size of wire, a No. 8, and check for voltage drop.

$$\text{Voltage drop with No. 8 wire} = \frac{24 \times 15 \times 100}{16{,}510} = 2.18 \text{ volts}$$

Since this voltage drop is less than the allowable amount, two No. 8 wires should be used.

Example.—Determine the proper size of wire for the three-wire, 115/230-volt, d-c main of the first example under Sec. **52**. The length of the circuit is 150 ft. The wires are to be rubber covered, Type R, and installed in conduit. The installation has only a main and branch circuits, no feeder.

Solution.—From Sec. **52**.

$$\text{Present load on more heavily loaded outside wire} = 80.3 \text{ amp.}$$

$$\text{Future load on more heavily loaded outside wire} = 97.0 \text{ amp.}$$

From Sec. **58** and Table 4 of Div. 11 minimum allowable load $= 2.0 \times 10{,}000 \times 1.0$

$$= 20{,}000 \text{ watts}$$

$$\text{Minimum allowable current in outside conductor} = \frac{20{,}000}{2 \times 115} = 87 \text{ amp.}$$

Since the future load is greater than the minimum allowable load, the future load on the more heavily loaded side of 97 amp. will be used in determining the size of wire according to both carrying capacity and voltage drop.

From Table 18A of Div. 11 a No. 1 wire is required for the outside conductors in order to carry 97 amp.

Since the current in the outside conductors is less than 200, the current in the neutral wire will be taken the same as that of the outside wires, and the size of the neutral required according to carrying capacity will be No. 1, the same as the outside conductors.

From Table 37 of Div. 11 a voltage drop of 2.3 volts is allowable on the lamps.

From Table 39 of Div. 11 the effect of inductance can be neglected for a lighting circuit using No. 1 wire on a 60-cycle system.

$$\text{Voltage drop across lamps (Sec. 66)} = \frac{1}{2} \times \frac{24 \times 97 \times 150}{83{,}690}$$
$$= 2.07 \text{ volts}$$

Since this voltage drop is less than the allowable amount, all three of the wires should be No. 1.

Example.—Determine the proper size of wire to use for a branch motor circuit supplying a 10-hp., 440-volt, three-phase, squirrel-cage induction motor on continuous duty. The motor is of the normal-starting-current, normal-torque type started with reduced voltage. It is a 60-cycle system. The length of the circuit is 50 ft. The wires are to be rubber-covered, Type R, installed in conduit.

Solution.—From Table 9 of Div. 11 the full-load current = 14 amp.

$$125 \text{ per cent of the full-load current} = 14 \times 1.25 = 17.5 \text{ amp.}$$

From Table 18A of Div. 11 a No. 12 wire is required to carry 17.5 amp.

From Table 37 of Div. 11, 4.4 volts drop is allowable.

From Table 39 of Div. 11 the effect of inductance can be neglected for a 60-cycle motor circuit using No. 12 wire.

The voltage drop on a two-wire, d-c circuit carrying 14 amp. (full-load current) over a No. 12 wire for 50 ft. $= \frac{24 \times 14 \times 50}{6{,}530} = 2.58$ volts

$$\text{Voltage drop of actual circuit} = 0.866 \times 2.58 = 2.24 \text{ volts}$$

Since this drop is less than the allowable amount, three No. 12 wires should be used.

Example.—Determine the proper size of wire to use for a branch motor circuit supplying a series-wound, d-c motor on a 30-min. rating varying duty. The motor is a 15-hp., 230-volt machine. The length of the circuit is 100 ft. The wires are varnished-cambric insulated and installed in conduit.

Solution.—From Table 6 of Div. 11 the full-load current is 56 amp.

Since it is a short-time-duty service, referring to Table 10 of Div. 11, use 150 per cent of the full-load current in determining size of wire according to carrying capacity.

From Table 18A of Div. 11 a No. 4 wire is required to carry $(1.50 \times 56) = 84$ amp., when using varnished-cambric wire.

From Sec. **37** of Div. 11, 4.4 volts drop is allowable.

In determining voltage drop use full-load current.

$$\text{Voltage drop} = \frac{24 \times 56 \times 100}{41{,}740} = 3.22 \text{ volts}$$

Since this drop is less than the allowable amount, two No. 4 wires would be used.

Example.—Determine the proper size of wire to use for a three-wire, three-phase, 440-volt, 60-cycle feeder supplying five 10-hp. motors, six 15-hp. motors, and two 50-hp. motors. All the motors are of the normal-torque, normal-starting-current, squirrel-cage type, started with reduced voltage. It is a 60-cycle circuit, 200 ft. long. The wires are installed open with a regular flat spacing of 6 in. Slow-burning insulation is employed on the wires. Permission to use a demand factor of 0.6 has been obtained from the officials enforcing the Code.

Solution.—From Table 9 of Div. 11 the full-load current of a 10-hp. motor of this type is 14 amp.; of a 15-hp. motor, 20 amp.; and of a 50-hp. motor, 63 amp.

Using the formula of Sec. **60,**

Starting current of 50-hp. motor (Sec. **14** of Div. 11) = $2.0 \times 63 = 126$ amp.

Maximum-demand starting current of feeder

$$= [(5 \times 14) + (6 \times 20) + (1 \times 63)] \times 0.6 + 126 = (253 \times 0.6) + 126 = 278 \text{ amp.}$$

Maximum-demand running current of feeder

$$= [(5 \times 14) + (6 \times 20) + (1 \times 63)]0.6 + (63 \times 1.25) = (253 \times 0.6) + 79 = 231 \text{ amp.}$$

From Table 18 of Div. 11 a No. 1/0 wire is required to carry 231 amp. (maximum-demand running current), if slow-burning insulation is employed.

From Sec. **37** of Div. 11, 17.6 volts drop is allowable.

The effective spacing of the wires (Sec. **40,** Div. 11)

$$= 1.26 \times 6 = 7.56$$

From Sec. **39** of Div. 11 the effect of inductance cannot be neglected.

Determine the voltage drop according to method given in Sec. **79** using the maximum-demand running current.

Voltage drop of a two-wire, d-c circuit carrying 231 amp. 200 ft. over No. 1/0 wire

$$= \frac{24 \times 231 \times 200}{105{,}560} = 10.5 \text{ volts.}$$

Ratio of reactance to resistance for No. 1/0 wires spaced 8 in. apart on a 60-cycle circuit (Table 42 of Div. 11) = 0.9.

Power factor of circuit (Sec. **70** and Table 41, Div. 11):

$$\begin{aligned} 5 \times 10 \times 0.86 &= 43.0 \\ 6 \times 15 \times 0.86 &= 77.4 \\ 2 \times 50 \times 0.89 &= 89.0 \\ &\overline{209.4} \end{aligned}$$

$$\text{P.f.} = \frac{209.4}{240} = 87.5$$

Drop factor of circuit from Table 44 of Div. 11 for a ratio of reactance to resistance of 0.9 and a power factor of 0.875 = 1.34.

Voltage drop of circuit = $0.866 \times 1.34 \times 10.5 = 12.2$ volts.

Since this drop is less than the allowable amount use three No. 1/0 wires.

83. In determining circuit lengths from drawings or blueprints a long piece of tough paper divided (see Fig. 36) into the same measure as

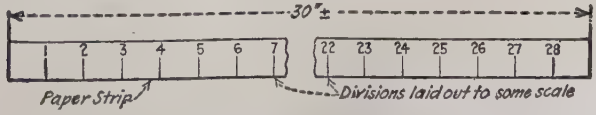


FIG. 36.—Paper scale for measuring circuit lengths.

the drawing can be effectively used in scaling distances. Always allow for rises or drops for wall outlets. The rotometer (Fig. 37), is a conven-

ient tool for scaling distances. The little wheel is run over the course of the circuit. The pointer indicates feet direct for drawings of certain scales. For other scales the dial reading must be multiplied by a constant to obtain actual lengths.

84. Indicating Loads on Diagrams.—In computing the ampere loads on circuits, if drawings are available, it is good practice to note the amperes

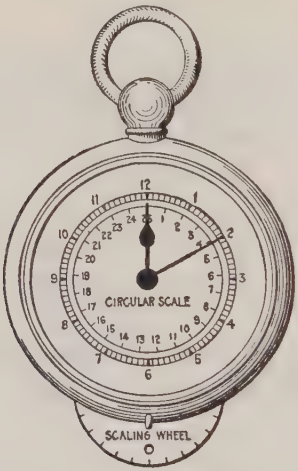


FIG. 37.—A rotometer.

of the loads on the drawings alongside the circuits. It is good practice to indicate both the present and the estimated future loads, one colored pencil being used for the present load and another color for the future loads.

85. Use of Tables in Circuit Calculations.—If tables that will give the values of loads, voltage drops, etc., are laid out when circuit calculations are made, much time may be saved in checking over the size of circuits or in making changes in the system. A typical table is given in the following article.

86. Branch Lighting Circuits

Panel	Branch circuit	Present load, amp.	Future load, amp.	Size wire according to carrying capacity	Length, ft.	Volts drop	Size wire to use	Remarks
A	1	10.0	13.1	No. 14	50	3.50	No. 10	No. 10 used to keep drop to 1.39
.....	2	7.8	9.2	No. 14	25	1.23	No. 14	
.....	3	9.1	11.6	No. 14	30	1.86	No. 12	To keep voltage drop down
.....	4	8.0	10.0	No. 14	20	1.07	No. 14	
B	etc.		43.9					

87. The question of energy loss in a circuit should not be slighted in circuit calculations.—It is well known that, in overcoming resistance, electrical energy is wasted; and as it costs money to develop or buy electrical energy, it is evident that in any commercial system such waste must be kept to a minimum. This may be done by decreasing the resistance of the conductors or, what amounts to the same thing, increasing the size of the conductors. Inasmuch as this is also an expensive matter, care must be exercised that the additional sum added to the expenditure in copper (and conduit if used) is not so excessive as to more than counterbalance the cost of the energy continually saved.

88. Conductor economy in interior wiring installations should always be considered as a matter subordinate to the National Electrical Code and permissible-voltage-drop requirements. Obviously, any conductor selected for a specific installation must fulfill the requirements of mechanical strength, ample carrying capacity, and permissible voltage drop. Frequently one of these three considerations will definitely determine the size of the conductor; however, a calculation may show that the resistance or I^2R (power) loss is excessive. Then it may be desirable to use a larger size of conductor than would otherwise be necessary.

89. Annual charges may be considered, in connection with the economical selection of a conductor size, as being made up of two items: (*a*) **resistance-loss charges** and (*b*) **investment charges.** Resistance-loss charges depend upon the resistance, the current, and the unit cost of energy and may be decreased by an increase of conductor size. This, however, calls for a greater investment with correspondingly larger investment charges. A conductor should, for maximum economy, be selected of such a size that the total annual charge will be a minimum. In Fig. 38 the effect of a variation of conductor size on resistance-loss charge,

investment charge, and total annual charge is shown graphically for wires not installed in raceways. The interest charges on the conductor increase directly with its cross-sectional area (curve A, Fig. 38). If the wires were installed in conduit, the cost of the conduit and fittings should be added to the conductor cost. The resistance-loss charges decrease inversely as the cross-sectional area of the conductor (curve B, Fig. 38). The total annual charge (curve C, Fig. 38), the sum of curves A and B, is at its minimum value directly over the point where curves A and B intersect. That is, the conductor size which will have the least total annual cost is that one for which the annual interest charge equals the annual resistance-loss charge. This proposition has been demonstrated mathematically by Lord Kelvin.

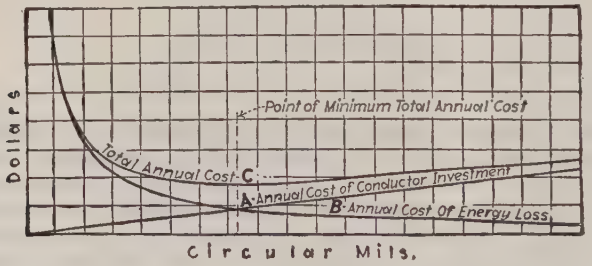


FIG. 38.—Graph illustrating Kelvin's law.

90. Kelvin's law was deduced in 1881 by Sir William Thomson (Lord Kelvin). The original law was modified into the following more exact form by Gilbert Kapp. "The most economical area of conductor is that for which the annual cost of energy wasted is equal to the interest on that portion of the capital outlay which can be considered proportional to the weight of copper used." On the basis of the above law it can be shown that

$$\text{Cir. mils} = 55{,}867 \times I \times \sqrt{\frac{C_e}{C_c \times A}} \qquad (30)$$

For derivation see "The Electrical Engineer's Pocketbook" (International Textbook Company). See also "Transmission of Electrical Energy," by A. V. Abbot; "Electric Power Transmission," by Dr. Louis Bell; and "Overhead Electric Power Transmission," by Alfred E. Still.

where cir. mils = area, in circular mils, of the most economical conductor; I = the mean annual current. C_e = cost of energy per kilowatt-hour, in dollars; C_c = cost of copper, in dollars, per pound installed; and A = annual charge, in percentage, of the cost of the conductor. This can ordinarily be assumed to be about 10 per cent. Note that the length of the circuit is not a factor in the equation. The above equation is best adapted to the solution of cases where the conductors are not insulated.

The method of the following paragraph should always be used to check it.

91. Method of Determining Economical Conductor Size.—The method involves the preparation of a table, as shown below, showing energy cost and interest cost of an arbitrarily chosen length of conductor for a number of sizes of conductor. The cost per unit length of conductors (preferably 1,000 ft. or 305 m.) may be obtained from the manufacturers' wire lists. For conduit installations the corresponding cost of conduit and fittings should be added to the cost of conductors. The cost of energy lost may be computed from the equations of Sec. **92** or from Sec. **93.** By use of a comparative table, as shown below, costs are effectively shown, and a decision may be speedily reached. This method may be used as a check upon Kelvin's-law equation. In the table, the least total annual cost is $12.33. Hence a 4/0 conductor is, for this case, the one of maximum economy.

Size of rubber-covered conductor	No. 3/0 wire	No. 4/0 wire	250,000 cir. mil wire	300,000 cir. mil wire
Cost of 400 ft. of conductor	$70.00	$86.40	$102.40	$118.40
Annual charges on above cost at 10 per cent.	$ 7.00	$ 8.64	$ 10.24	$ 11.84
Cost of energy lost in conductor at 2 cts. per kw.-hr	$ 5.94	$ 3.69	$ 2.64	$ 2.27
Total annual cost of conductor	$12.94	$12.33	$ 12.88	$ 14.11

92. Cost of Energy Lost.—Taking 12 ohms as the resistance of a circular mil-foot of commercial copper wire at 50°C., the power loss in any conductor may be found thus:

$$P = \frac{12 \times I^2 \times L}{\text{cir. mils}} \tag{31}$$

where P = power lost in the conductor in watts; I = the mean annual current in amperes in the conductor; L = length of the conductor in feet; and circular mils = area of the conductor in circular mils.

The cost of energy lost can be computed from the following formula:

$$\text{Cost of energy lost per year in dollars} = \frac{N \times P \times 8{,}760 \times R}{1{,}000 \times 100} \tag{32}$$

where N = number of conductors; P = power loss in one conductor; and R = cost of electric energy in cents per kilowatt-hour. In the formula, the 8,760 is the number of hours in a year; the 1,000 is the factor to change watts to kilowatts; and the 100 changes cents to dollars.

93. Cost of Energy Lost for 500 Hr. of Operation with Cost of Electrical Energy at 2 Ctsper Kilowatt-hour

Wire size, A.w.g.	Length of run, ft.	Load, amp.[a]													
		6	10	15	20	25	30	35	40	50	60	70	80	90	100
14	50	$0.10	$0.26	$0.60											
	100	0.19	0.52	1.20											
	200	0.38	1.04	2.40											
	300	0.57	1.06	3.60											
12	50	0.06	0.16	0.36	$0.64										
	100	0.12	0.32	0.72	1.28										
	200	0.24	0.64	1.44	2.56										
	300	0.36	0.96	2.16	3.84										
10	50	0.04	0.10	0.22	0.40	$0.62	$0.90								
	100	0.08	0.20	0.45	0.80	1.24	1.80								
	200	0.16	0.40	0.90	1.60	2.48	3.60								
	300	0.24	0.60	1.35	2.40	3.72	5.40								
8	50	0.03	0.06	0.15	0.25	0.40	0.60	$0.77	$1.06						
	100	0.05	0.12	0.30	0.50	0.80	1.20	1.54	2.12						
	200	0.09	0.24	0.60	1.00	1.60	2.40	3.08	4.24						
	300	0.14	0.36	0.90	1.50	2.40	3.60	4.62	6.36						
6	50	0.02	0.04	0.09	0.16	0.25	0.36	0.49	0.64	$1.00	$1.44				
	100	0.03	0.08	0.18	0.32	0.50	0.72	0.98	1.28	2.00	2.88				
	200	0.06	0.16	0.36	0.64	1.00	1.44	1.76	2.56	4.00	5.76				
	300	0.09	0.24	0.54	0.96	1.50	2.16	2.64	3.84	6.00	8.64				
4	50	0.01	0.03	0.06	0.08	0.15	0.22	0.32	0.40	0.62	0.90	$1.22	$1.60		
	100	0.02	0.05	0.12	0.16	0.30	0.44	0.64	0.80	1.24	1.80	2.44	3.20		
	200	0.04	0.10	0.24	0.32	0.60	0.88	1.28	1.60	2.48	3.60	4.88	6.40		
	300	0.05	0.15	0.36	0.48	0.90	1.32	1.92	2.40	3.72	5.40	7.32	9.60		
2	50	...	0.02	0.04	0.06	0.10	0.13	0.18	0.24	0.40	0.60	0.77	1.00	$1.26	$1.60
	100	0.01	0.03	0.07	0.12	0.20	0.25	0.36	0.48	0.80	1.20	1.54	2.00	2.52	3.20
	200	0.02	0.06	0.14	0.24	0.40	0.50	0.72	0.56	1.60	2.40	3.08	4.00	5.04	6.40
	300	0.04	0.10	0.21	0.36	0.60	0.75	1.08	1.44	2.40	3.60	4.62	6.00	7.56	9.60

[a] Unfilled spaces at the right are beyond the allowable current-carrying capacity (in amperes) of rubber-insulated wire.

$$\text{Cost of energy lost per year in dollars} = \frac{H \times R \times K}{500 \times 2} \qquad (33)$$

where H = hours of operation of circuit per year; R = cost of electrical energy in cents per kilowatt-hour; K = dollars as obtained from table for size of wire, current, and length of run. The table and formula may be

used for d-c or single-phase, a-c circuits. If the load on a three-wire, d-c or single-phase, a-c circuit is nearly balanced, the formula will give satisfactory results if the current is taken as the current in the more heavily loaded wire.

94. Factors for Determining the Mean Annual Current.—To ascertain the mean annual current for substitution in the Kelvin's-law equation Eq. (30), or in Eq. (31) of Sec. **92** multiply the maximum current by the ratio applying to the conditions under consideration, which is given in the column headed "Factor" in the following table. The table is calulated on a basis 24 hr. × 365 days = 8,670 hr. per year.

Example.—If a maximum current of 1,000 amp. (I) flows ¾ of the time or 6,570 hr. per year and a current of 750 amp. ($\frac{3}{4}I$) flows ¼ of the time or 2,190 hr. per year the factor 0.944 would be used. That is, 0.944 × 1,000 amp. = 944 amp. = mean annual current for substitution in Kelvin's-law equation.

Proportion of time current is carried					Factor
	Proportion of maximum current I carried				
	¼I	½I	¾I	I	
	0	0	0	1	1.000
	0	0	¼	¾	0.944
	0	¼	0	¾	0.901
	0	0	½	½	0.844
	0	0	0	¾	0.866
	¼	0	0	¾	0.875
	0	¼	¼	½	0.838
	0	0	¾	¼	0.820
	¼	0	¼	½	0.810
	0	½	0	½	0.790
	0	¼	½	¼	0.771
	¼	¼	0	½	0.760
	¼	0	½	¼	0.744
	½	0	0	½	0.729
	0	½	¼	¼	0.718
	0	0	0	½	0.707
	¼	¼	¼	¼	0.685
	0	¾	0	¼	0.661
	½	0	¼	¼	0.650
	¼	½	0	¼	0.611
	½	¼	0	¼	0.586
	¾	0	0	¼	0.545
	0	0	0	¼	0.500

DIVISION 4

GENERAL ELECTRICAL EQUIPMENT AND BATTERIES

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INTRODUCTION

1. Introduction.—In this division the miscellaneous equipment, materials, and devices which are employed for electrical installations are discussed. Certain items which are used for specific types of installations have not been included in this division, but explanation of these devices or materials will be found in Div. 8 on Outdoor Distribution or in Div. 9 on Interior Wiring. Since there is so much material to cover for generators, motors, and transformers, a separate division (Div. 7) has been devoted to generators and motors and another (Div. 5) to transformers.

The aim in the preparation of Div. 4 has been to present the different types of equipment, materials, and devices which are available, with sufficient explanation of their characteristics, installation, and maintenance so that proper equipment may be intelligently selected, installed, and maintained in good condition for satisfactory service. Much useful information that is not ordinarily readily available at short notice has been included.

SWITCHES

2. A switch is a device for making, breaking, or changing connections in an electric circuit under the conditions of load for which it is rated. It is not designed for interruption of a circuit under short-circuit conditions. Refer to Sec. **62** for discussion of difference between circuit breakers and switches.

3. Switches may be classified in several different ways as follows:

I. According to number of poles.
- *A*. Single pole.
- *B*. Two or double pole.
- *C*. Three or triple pole.
  1. Standard.
  2. Solid neutral.
- *D*. Four pole—standard.
- *E*. Four pole—solid neutral.
- *F*. Five pole—standard.
- *G*. Five pole—solid neutral.

II. According to number of closed positions.
- *A*. Single throw.
- *B*. Double throw.

III. According to type of contact.
- *A*. Knife blade.
- *B*. Butt contact.
  1. Single line.
  2. Multiple line.
  3. Surface.
- *C*. Mercury.

IV. According to number of breaks.
- *A*. Single break.
- *B*. Double break.

V. According to method of insulation.
- *A*. Air break.
- *B*. Oil immersed.

VI. According to method of operation.
  A. Operating force.
    1. Manual.
    2. Magnetic.
    3. Motor or solenoid.
  B. Mechanism.
    1. Lever.
    2. Dial.
    3. Drum.
    4. Snap.
      a. Tumbler.
      b. Rotary.
      c. Push button.

VII. According to speed of operation.
  A. Ordinary.
  B. Quick break.
  C. Quick make.

VIII. According to enclosure.
  A. Open.
  B. Enclosed.
    1. General purpose.
    2. Driptight.
    3. Weather resisting.
    4. Watertight.
    5. Dusttight.
    6. Submersible.
    7. Hazardous locations.
    8. Bureau of Mines.

IX. According to protection provided to circuits or apparatus.

X. According to type of service.
  A. Power switches.
    1. General purpose
      a. Open.
      b. Safety.
    2. Disconnecting.
    3. Motor circuit.
    4. Motor starting.
    5. Field switches.
    6. Service entrance.
  B. Wiring switches.
    1. According to method of installation.
      a. Flush mounting.
        (1) Standard.
        (2) Interchangeable.
        (3) Combination.
      b. Surface.
      c. Pendant.
      d. Through cord.
      e. Door.
      f. Canopy.
      g. Appliance.
      h. Special exposures.
    2. According to function.
      a. General purpose.
        (1) Single pole.
        (2) Double pole.
      b. Three way.
      c. Four way.
      d. Three or four pole.
      e. Multiple circuit or electrolier.
      f. Momentary contact.
      g. Heater.
  C. Control switches.
  D. Instrument switches.
  E. Miscellaneous types.

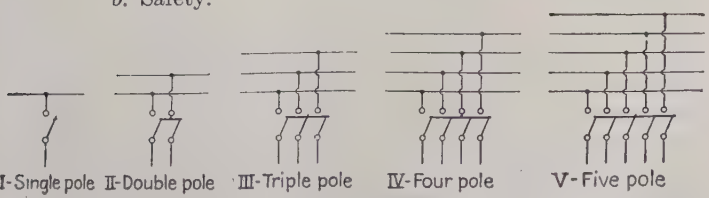


FIG. 1.—Illustrating meaning of poles.

4. A pole of a switch is that part of a switch which is used for the making or breaking of a connection and which is electrically insulated from

other contact-making or -breaking parts. A single-pole switch will make or break the connections in only one conductor or leg of a circuit; a two-pole switch in two legs, etc. Schematic diagrams illustrating the meaning of number of poles are shown in Fig. 1.

For some installations in systems having a grounded neutral wire, it may be desirable not to break the neutral connection as the circuit passes through a switch. For these cases, a regular switch with a number of

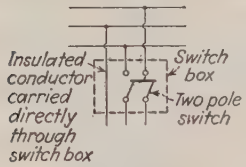
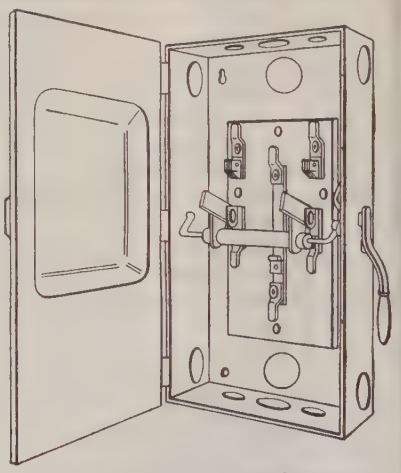


FIG. 2.—Two-pole switch used with three-conductor, grounded neutral circuit.

I. Schematic diagram of three-pole solid-neutral switch.



II. Three-pole, unfused switch.

FIG. 3.—Solid-neutral switch and connections.

poles one less than the number of conductors of the circuit may be used. The neutral conductor is then carried directly through the switch box without any connection to the switch (Fig. 2). Frequently a neater installation and one that is easier and quicker to install can be made by the use of what is called a solid-neutral switch (Fig. 3). The number of switch blades or contacts for a solid-neutral switch is one less than the number of conductors of the circuit, but a neutral strap is located between two of the switch blades or contacts for carrying the neutral leg solidly through the switch without breaking the circuit of the neutral conductor. A switch designated as a three-pole, solid-neutral switch will accommodate a three-conductor circuit and provides two switched poles and one solid neutral strap. A solid-neutral switch is shown in Fig. 3, II.

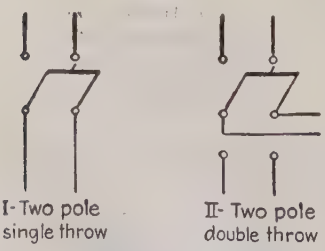


FIG. 4.—Illustrating single- and double-throw switches.

5. A single-throw switch (Fig. 4, I) is one which will make a closed circuit only when the switch is thrown in one position. A **double-throw switch** (Fig. 4, II) will make a closed circuit when thrown in either of two positions. Special **multiple-throw switches** can be made to meet the requirements of special conditions which require that the switch make a closed circuit when thrown in more than two positions. Some examples of multiple-throw switches are the dial and drum switches employed for control and instrument work.

6. Switch Contacts.—In the construction of switches, different methods are employed for making contact between the movable and stationary parts of the poles. **Knife-blade** switches consist of some form of movable copper blade which makes contact by being forced between forked contact jaws as illustrated in Fig. 5.

The manner of constructing the contact members of **butt-contact** switches varies widely with different manufacturers. In all cases, however, the contact is formed by pressing the movable member against the stationary contact. (The two contacts are butted together when closed.) The two members are so constructed that there will be a stiff spring action

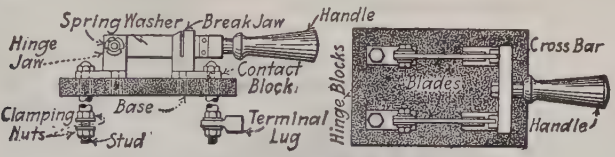
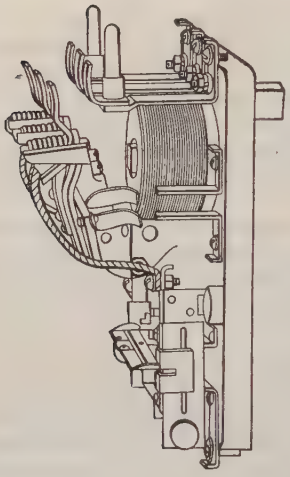


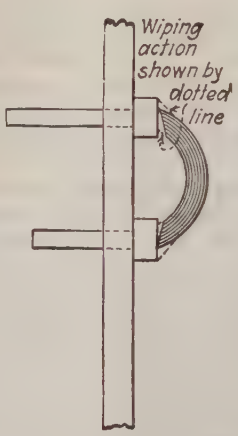
FIG. 5.—Names of knife-blade switch parts.

between them in order to ensure a good contact when in the closed position. The contact formed between the two members may be of the **single-line, multiple-line,** or **surface** type. **Single-line** contact is obtained by making the surface of the contacting members in a curved form so that, when closed, the members are in contact only along a single line instead of over the entire surface. With **multiple-line** contacts the two members are not in contact over their entire surfaces, but contact is made along several lines. The multiple lines of contact are obtained by making the movable member of laminated (brush) or cylindrical construction. In butt-contact switches of the **surface** type, the contact members when in the closed position are butted together so that they are in contact over as much of the entire surface as possible. The disadvantage of the surface type of contact is that it is very difficult to obtain a good contact over the entire surface. Typical butt-contact constructions are illustrated in Fig. 6.

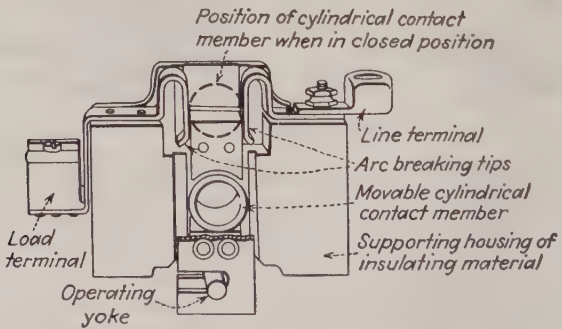
One of the essential functions of any switch is to maintain a good low-resistance contact when in the closed position. If the contact is poor, there will be considerable resistance at this point. The high contact resistance will result in overheating of the switch and possible opening



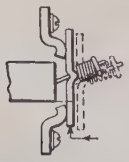
I. Single-line contact on a magnetic switch (single break).



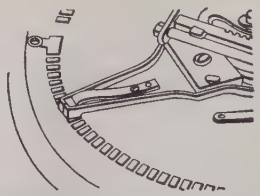
IV. Multiple-line contact with double break.



II. Single-line contact with double break (switch in open position).



III. Single-line contact (double break).

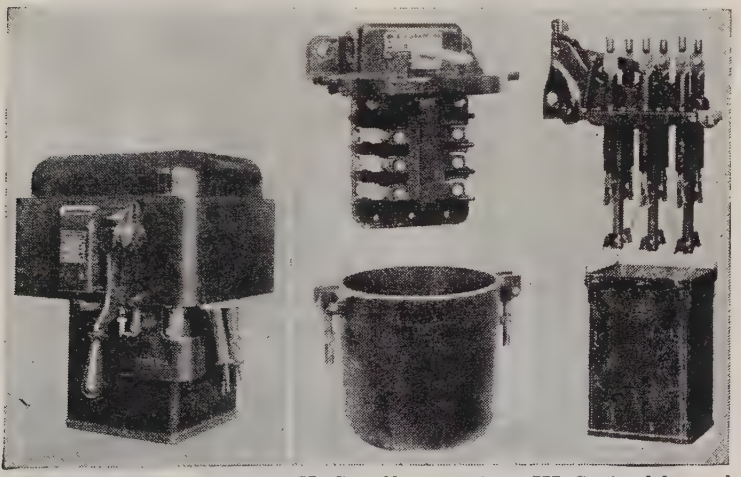


V. Surface contact for dial switch.

FIG. 6.—Butt-contact constructions.

of the circuit due to functioning of circuit-overload protective devices. Switches are generally constructed so that the contacts will be closed under pressure with a sliding or rolling action in order to maintain clean, low-resistance contacts. The contact surfaces are frequently silver plated in order to prevent oxidation and reduce contact resistance.

7. Mercury contact switches are used sometimes for low-capacity circuits in control and branch circuit wiring. They consist of a glass tube containing mercury and two stationary contact members located in opposite ends of the tube. The tube is mounted in a supporting case so that the position of the axis of the tube may be changed by means of an



I. Industrial type. II. Small-capacity, three-pole double throw. III. Switchboard type.

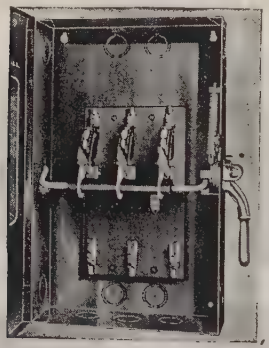
FIG. 7.—Oil switches.

operating handle. When the handle is in the "off" position, the axis of the tube is tilted so that the mercury is at one end of the tube and makes contact with only one of the stationary contacts. When the handle is thrown to the closed position, it rotates the tube, causing the mercury to move in the tube in a manner that closes the circuit from the stationary contact at one end of the tube through the mercury to the stationary contact at the other end of the tube. Refer to Secs. **30** and **32** for further information on wiring switches for interior wiring work.

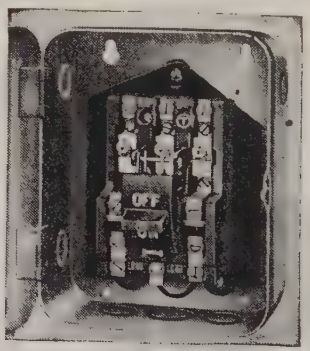
7A. Both knife-blade and butt-contact switches are made in single- and double-break types. A single-break type of switch, in opening, breaks each pole of the circuit at only one point. A double-break type of switch, in opening, breaks each pole of the circuit at two points. Breaking the circuit in two places doubles the quenching effect of the switch in

suppressing the arc. This reduction in the arcing at the contacts prolongs the life of the contacts by reducing the formation of destructive beads and pitted areas.

8. Insulation of Switches.—The great majority of switches are designed to interrupt the circuit in the surrounding air. The live parts must be spaced sufficiently far apart so that the air space between them will have sufficient insulating ability for the voltage which exists between the adjacent parts. Oil switches (Fig. 7) have the contact parts immersed in oil so that the circuit is interrupted under oil.

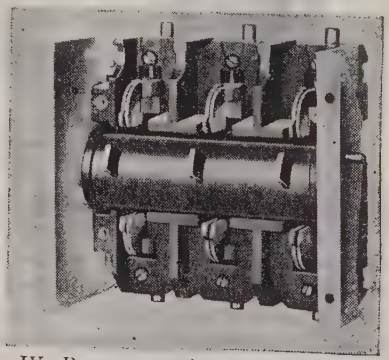


I. Lever and operating-arm mechanism.



II. Lever and toggle mechanism.

III. Single-pole toggle switch, 3,000 amp. at 750 volts d-c.

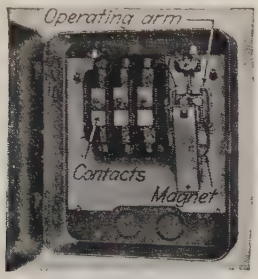


IV. Rotary motion operated by lever outside box.

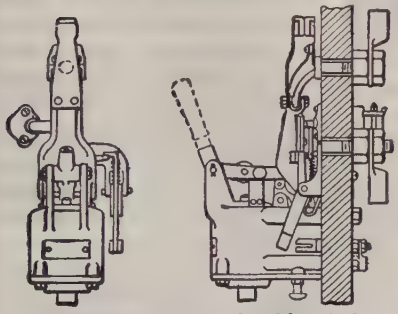
FIG. 8.—Operating mechanisms for manual switches.

9. Switches may be operated by hand (Fig. 8), by electromagnets (Fig. 9), by motors (Fig. 9), or by means of solenoids (Fig. 9). Most power switches are operated by means of simple lever action (Fig. 5) or by means of a lever attached to the switch through a toggle mechanism.

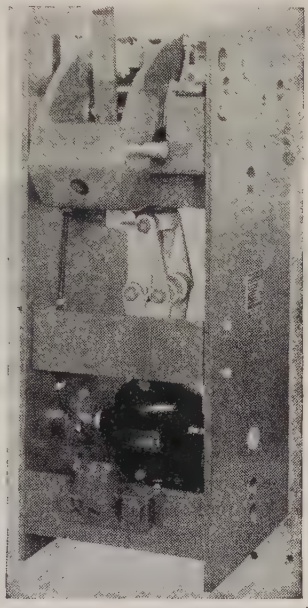
Dial switches consist of a movable contact, mounted on a rotatable arm, and several fixed contacts arranged in circular form. As the arm is rotated the movable contact makes connection with the successive fixed



Electromagnet-operated switch.



II. Solenoid-operated field switch.



III. Motor-operating mechanism for oil circuit breaker.

FIG. 9.—Electrically operated switches.

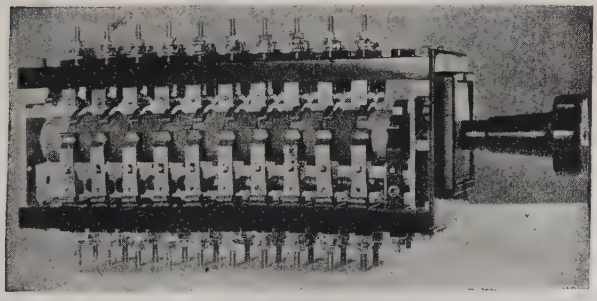


FIG. 10.—Drum-type instrument switch.

contacts, one at a time. This type of switch is used for instrument; control; storage-battery, end-cell; and transformer tap-changing switches. Drum switches consist of a set of contact segments mounted on a central

movable drum and a set of stationary contact fingers (Fig. 10). Drum switches are employed for motor starting, control, and instrument switches.

Magnetic switches consist of switch contacts operated by means of an electromagnet. They are used extensively as the switching element for motor controllers. They also find application in general wiring work, when it is desired to control a circuit at some point remote from the location of the switch.

Snap switches are small-capacity switches in which the circuit is made or broken with a quick motion independent of the speed of operation of the switch by the operator. In the rotary type of snap switch (Fig. 11), the switch blades are given a rotary motion by means of the handle or button through a spring-and-cam mechanism. The blades of a push-button switch (Fig. 12) are operated by a rocking action imparted to them by means of the push button through a spring-and-cam mechanism. The tumbler or toggle switch (Fig. 13) is operated in a manner similar to the push-button switch except that the blades are actuated by means of a lever instead of a button.

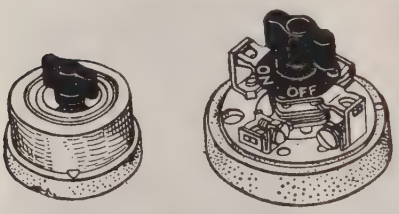


FIG. 11.—Rotary snap switch—surface-mounting type.

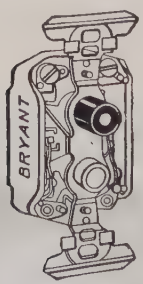


FIG. 12.—Push-button switch. Flush-mounting type. (*Bryant Electric Co.*)

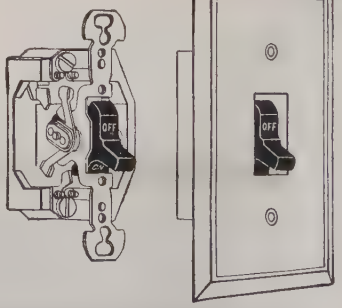


FIG. 13.—Toggle or tumbler switch. Flush-mounting type (*Harvey Hubbell, Inc.*)

10. Speed of Operation of Switches.—With an ordinary manual switch the speed of closing or of opening a switch is dependent upon the operator. Where current conditions are such that an arc may be drawn, attachments should be provided which make it impossible to open the switch slowly and thus draw a dangerous arc. The National Electrical Code requires

that all 600-volt knife switches designed for breaking currents over 200 amp. shall be equipped for quick-break action. The Code recommends that all d-c switches rated at over 200 volts be so equipped. Many switches are provided with quick-make features as well as quick-break. A quick-break attachment for an open knife switch is shown in Fig. 14. When the switch is opened, the auxiliary blade is held in the switch jaws by friction until after the main blade has been withdrawn. Withdrawal of the main blade increases the spring tension so that it suddenly jerks the auxiliary blade out of the jaws and quickly breaks the circuit. In switches of the enclosed safety type, the operating handle is frequently connected through linkages and a spring so that after the handle has been moved a certain distance the spring quickly completes the closing or opening action, giving the switch quick-break or make features.

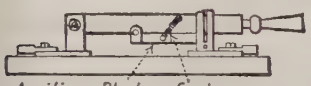


FIG. 14.—A quick-break switch.

11. Enclosure of Switches.—Switches may be classified as open or enclosed, depending upon whether their current-carrying parts are exposed or enclosed in a protecting box or casing. All switches should be of the enclosed type (externally operated) unless they are mounted on switchboards or panel boards. Even in these cases it is generally better practice to use switchboards and panel boards of the dead-front-construction type. In no case should open switches be employed where they may be operated by unqualified persons.

Switches may be obtained with enclosures to meet the requirements of different classes of exposures. The standard N.E.M.A. types of non-ventilated enclosures are as follows:

TYPE I. GENERAL-PURPOSE.—A sheet-metal case designed to meet the Underwriters' Laboratories' general specifications for enclosures as may be in effect from time to time, and primarily to protect against accidental contact.

Type I case is suitable for general-purpose application, indoors, and where atmospheric conditions are normal. It serves as protection against dust and light indirect splashing but is not dusttight.

TYPE II. DRIPTIGHT.—A sheet-metal case similar to Type I, with the addition of drip shields or their equivalent.

Type II case is suitable for application where condensation may be severe, as in cooling rooms and laundries.

TYPE III. WEATHER RESISTING.—A case of cast construction, or of sheet metal of suitable rigidity, with proper protection against weather hazards, as rain and sleet.

Type III case is suitable for outdoor application, as on docks, canal locks, and construction work, and also for application in subways and tunnels.

TYPE IV. WATERTIGHT.—A case of cast construction, or of sheet metal, of suitable rigidity, and designed to meet the following hose test:

A stream of water from a hose (not less than 1 in. in diameter) under a head of about 35 ft. when played upon the apparatus from a distance of about 10 ft. for several minutes must not produce leakage.

Type IV case is suitable for application outdoors, on ship docks, and in dairies, breweries, etc.

Type V. Dusttight.—A case of cast construction, or of sheet metal of suitable rigidity, and provided with gaskets or the equivalent to exclude dust. It meets the requirements of the National Electrical Code for Class III and IV locations as may be in effect from time to time.

Type V case is suitable for application in steel mills, cement mills, and other locations where it is desirable to exclude dust.

Type VI. Submersible.—A case designed to meet the requirements of operation under water for specified conditions of pressure and time.

Type VI case is suitable for application where it may be subject to submersion in water, as in quarries, mines, and manholes. The design will depend on the specified conditions of pressure and time.

a. Wiping joints for cable connection may be provided as an option.

Type VII. Hazardous Locations—Class I—Air Break.—A case designed to meet the application requirements of the Code for Class I, Group D hazardous locations as may be in effect from time to time and designed in accordance with the Underwriters' Laboratories' specification as may be in effect from time to time.

Type VIII. Hazardous Locations—Class I—Oil Immersed.—A case designed for the application requirements of the Code for Class I, Group D, hazardous locations as may be in effect from time to time and designed in accordance with the Underwriters' Laboratories' specification as may be in effect from time to time, the apparatus being immersed in oil.

Type IX. Hazardous Locations—Class II.—A case designed for the application requirements of the Code for Class II hazardous locations as may be in effect from time to time and designed in accordance with the Underwriters' Laboratories' specifications as may be in effect from time to time.

Type X. Bureau of Mines.—A case designed to meet the requirements of the U. S. Bureau of Mines, as may be in effect from time to time.

Type X case is for application in coal mines.

Note I.—When an enclosure is required to meet gasproof or gastight requirements, the selection of a suitable type will depend on whether protection is desired against corrosion, or against explosion and fire.

Note II.—When an enclosure is required to meet acid-resistant or fume-resistant requirements, the design will depend on the conditions of exposure.

Note III.—For explanation of classes of hazardous locations, refer to Div. 9.

12. Overcurrent protection for circuits or apparatus is frequently incorporated with a switch. For the protection of circuits the protective device incorporated with the switch will consist of fuses. For the protection of equipment the protective device may be any one of the types listed in Sec. **44** (1, 2, 4, and 5). Fused switches are equipped with fuse

clips for accommodating standard cartridge fuses or in some cases Edison screw-base plug fuses.

Fused switches used on systems with a grounded neutral may have one less pole than the number of conductors of the circuit, or a solid-neutral or switching-neutral switch may be employed. In the first case, the neutral leg is not carried through the switch, but the neutral conductor is simply carried through the switch box in the space around the switch. A solid-neutral switch (Fig. 15) has one less blade or contact than the number of conductors of the circuit, with a neutral strap located in the space between two of the switch blades or contacts for carrying the neutral leg solidly through the switch without breaking the circuit of the neutral conductor. No fuse is located in the neutral leg. A switching-neutral switch (Fig. 16) has a blade or contact for each conductor of the circuit. The blade or contact for the neutral conductor is connected by means of a copper strap to its terminal without any fuse clips. Such a switch opens the neutral conductor leg when the switch is opened.

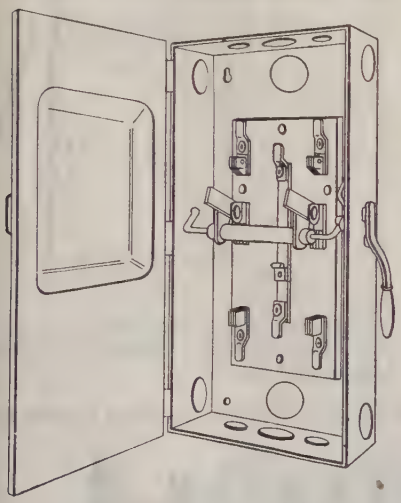


FIG. 15.—Three-pole, solid-neutral, fused switch. (*Trumbull Electric Mfg. Co.*)

13. General-purpose or general-use power switches are switches intended for use in general distribution and branch circuits. They are rated in amperes and are capable of interrupting their rated current at their rated voltage. They may be of the open or enclosed externally operated type. The enclosed switches are generally referred to as safety switches.

General-purpose or general-use power switches are designated as Type A, C, or D switches, depending upon the severity of service for which they are designed. **Type A** switches are the most ruggedly constructed switches of the three types and are designed for the heaviest duty service both with respect to frequency of operation and current capacity for handling heavy overloads. **Type C** switches are of lighter construction than Type A and are designed for service conditions where frequent operation is not required and where overload conditions are not severe. **Type D** switches are of light construction and are designed primarily for entrance service and general-purpose use where load is light and operation very infrequent

14. Open switches are switches constructed with their current-carrying parts exposed. Most open switches are of the plain lever knife-blade type. Knife-blade switches in very heavy current-carrying capacities are hard to operate owing to the large rubbing contact surfaces required. For this reason open switches of very large capacity are usually of the brush-butt-contact type (Fig. 8, III).

Most open-lever-type, knife-blade switches are of the single-break type and are made in a variety of different forms. They can be obtained in single-, double-, triple-, and four-pole types, for either front or rear connection (see Figs. 17 and 18). They may be of the fused or unfused type and either single or double throw.

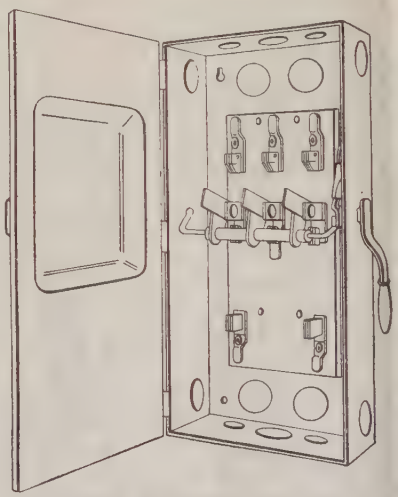


FIG. 16.—Three-pole, switching-neutral, fused switch. (*Trumbull Electric Manufacturing Co.*)

Open switches are used principally for mounting on panel boards or

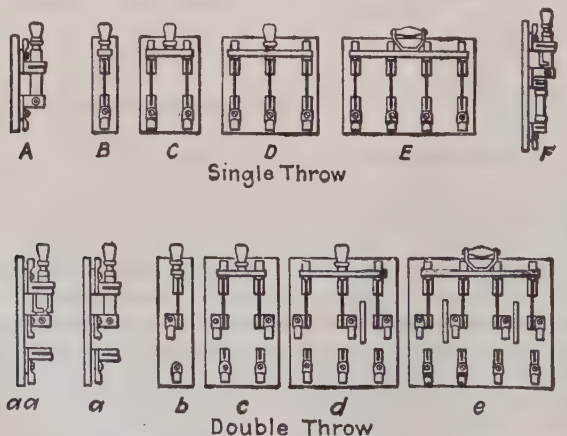


FIG. 17.—Front-connected knife-blade switches. ("*Electric System Handbook.*")

switchboards and occasionally for other purposes, when mounted inside enclosing boxes.

15. The names of knife-switch parts are given in Fig. 5. The contact between the break jaws and the blade should be carefully inspected, as it is at this point that knife switches are most apt to give trouble by overheating. The contact between the hinge jaws and the blade seldom limits the capacity of a switch, because it is under pressure from the hinge bolt and the spring washers. The capacity of a switch is determined by its temperature rise. The National Electrical Code specifies a maximum rise in any part of 50°F. at National Electrical full load.

About 1,000 amp. per sq. in. of copper section and 50 to 75 amp. per sq. in. of sliding contact surface is usually allowed in designing switches.

A switch that will carry, possibly, 1,000 amp. with a 20°C. temperature rise, will carry possibly 2,000 amp. with about a 60°C. rise. The radiation of heat from the switch increases more rapidly than does the rise in temperature, and as the heat generated varies as the square of the current, it is evident that the temperature rise will be somewhat less than proportional to the square of the current.

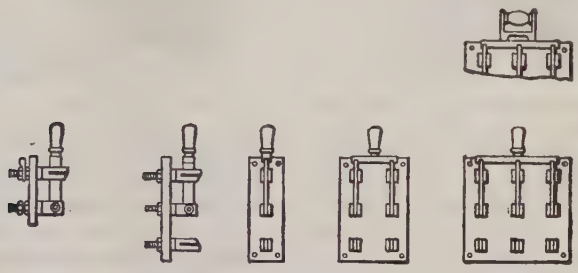


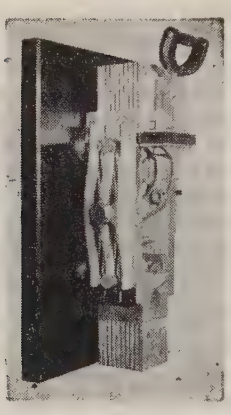
FIG. 18.—Rear-connected knife-blade switches. (*"Electric System Handbook."*)

With a given current, a switch will break about double the voltage with alternating current as with direct current. This is due to the fact that an alternating current decreases to a zero value during each cycle. The Code recognizes this and specifies that the spacings for 250 volts d.c. are also approved for 500 volts a.c.

The voltage drop from contact block to hinge block of a good switch should not exceed about 12 millivolts with full-load current.

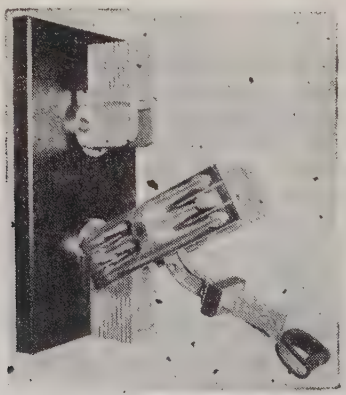
15A. A special form of open knife-blade switch is made by the I-T-E Circuit Breaker Co. It is called the Klamp-Tite Switch, Fig. 18*A*. This switch is so constructed that, as the switch is closed, a clamping action exerts a heavy equalized pressure on the top and bottom contacts. This pressure, together with the normal wiping action, ensures a good low-resistance contact.

16. Finish of Switches.—The copper parts of safety switches are frequently tin-plated in order to reduce the formation of copper oxide and



I. Closed position. The two side compression bars carry right- and left-hand threaded nuts into which a clamping bolt is rotated by the movement of the handle. This clamping action develops heavy equalized pressures on the top and bottom contacts.

II. Semi-closed position. In opening the switch the handle is moved to this position, rotating the clamping bolt and relieving the pressure on the contacts. The handle and blades latch together at this point in the stroke and the switch is opened in the conventional manner.



III. Open position. With the switch in the open position, clamping pressure is relieved. The blades are attached to the lower block by a floating hinge pivot. Switch adjustment is such that a wiping action is obtained at both top and bottom contacts. All contact surfaces are silvered.

FIG. 18A.—Klamp-Tite open knife-blade switch. (*I-T-E Circuit Breaker Co.*)

prevent corrosion. The contact parts of the better switches are either silver- or cadmium-plated in order to provide a better contact surface and thereby reduce the heating and ensure longer life.

Open knife switches may be furnished with the copper parts finished in different ways. The different finishes supplied by the Trumbull Electric Manufacturing Co., which are typical of the industry, are given below. An additional charge is made for special finishes.

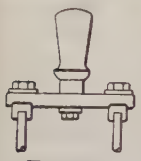


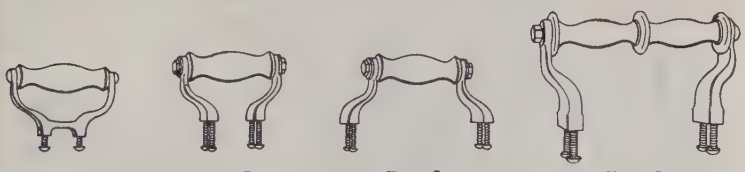
FIG. 19.—Straight handle on two-pole switch.

Standard Finish No. 1. Plain finish. This finish is applied to parts which are either acid-dipped or washed for the purpose of brightening or cleaning the surface. Parts may or may not be lacquered.

Standard Finish No. 2. Brush finish. These parts have a No. 100 emery rough polishing before fabrication and after fabrication are rough ground, *i.e.*, with No. 40 and then with No. 80 emery. They are then acid-dipped and lacquered. This finish is regularly supplied on Type A, front-connected switches.

Standard Finish No. 3. Polished finish. Metal is No. 100 emery rough-polished before fabrication and then ground, first with No. 40 and then with No. 150 emery. It is then polished, buffed, colored, and lacquered. This finish is regularly supplied on Type A, back-connected switches.

Special Finish No. 1. Satin or mat. The parts are ground with No. 100 emery before fabrication. Afterward they are rough-ground with



Unless otherwise specified Type B is furnished above 60 amp. capacity

FIG. 20.—Spade handles as supplied by the Trumbull Electric Manufacturing Co.

No. 40 emery and No. 100 emery on a wooden wheel. When necessary, a further grinding on the felt wheel with No. 150 emery is given. Then they are subjected to a power-driven wire brush to obtain the satinlike finish, and are lacquered. This finish is available at additional charge.

Special Finish No. 2. Draw file. The metal is No. 100 emery rough-polished before fabrication and then No. 40 emery-ground, followed by wooden wheel with No. 100 emery. Then the metal is polished and run under the No. 150 emery felt wheel, with lines on all parts running in the same direction. Finally, the metal is lacquered. This finish is available on request at additional charge.

17. Special Features for Open Knife Switches.—Two types of operating handles are available for open knife switches, the straight handle (Fig. 19) and the spade handle (Fig. 20). Straight handles are available in two types: regular and short. The short handles are used on high post switches for cabinet work. Spade handles are generally provided for the following switches:

Single-pole switches above 1,600 amp.

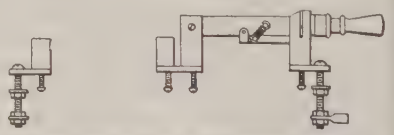
Two-pole switches of 800 amp. and above.

Three-pole switches of 800 amp. and above.

Three-pole switches of 600 volts (all amperages).

Four-pole switches.

I- Single pole low post with quick break attachment



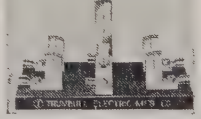
II- Single pole high post with quick break attachment

FIG. 21.—Open knife switches of the back-connected, fused type. (*Trumbull Electric Manufacturing Co.*)

Switches may be provided with either high or low posts as shown in Fig. 21. High-post switches will allow the switch when open to lie back over the fuses parallel with the mounting surface. Most switches may be provided with quick-break attachments if desired. Front-connected switches are generally furnished with slate bases, but ebony bases can be supplied on request.

Special attachments which are available for holding the switch in definite positions are shown in Fig. 22.

I. 90° Stop switch handle will not throw beyond 90°.

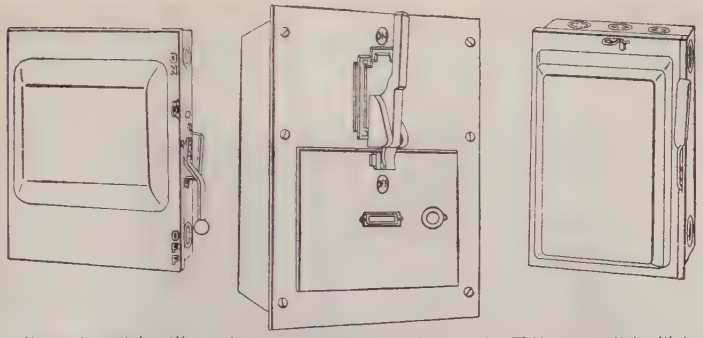


II. Double throw Type A switch equipped with open position catch.

III. Padlock attachment on Type A switch

FIG. 22.—Special attachments for open knife switches. (*Trumbull Electric Manufacturing Co.*)

18. Safety switches consist of a switch mounted inside a sheet-metal or cast-iron box and operated from outside the box by means of a handle connected to the switch mechanism. Various types are available with contacts of either the single- or double-break type employing either knife-blade or butt-contact construction. The operating handle may be located on the side of the switch box, in the center of the front cover, or in the front side of the box (see Fig. 23).



I- Type C switch with handle on side. (Trumbull Elec. Mfg. Co.)

II- Type A switch for switchboard mounting with handle in middle. (Trumbull Elec. Mfg. Co.)

III- Type A switch with handle in front side (Square D Co.)

FIG. 23.—Safety switches showing different types of operating handle arrangement.

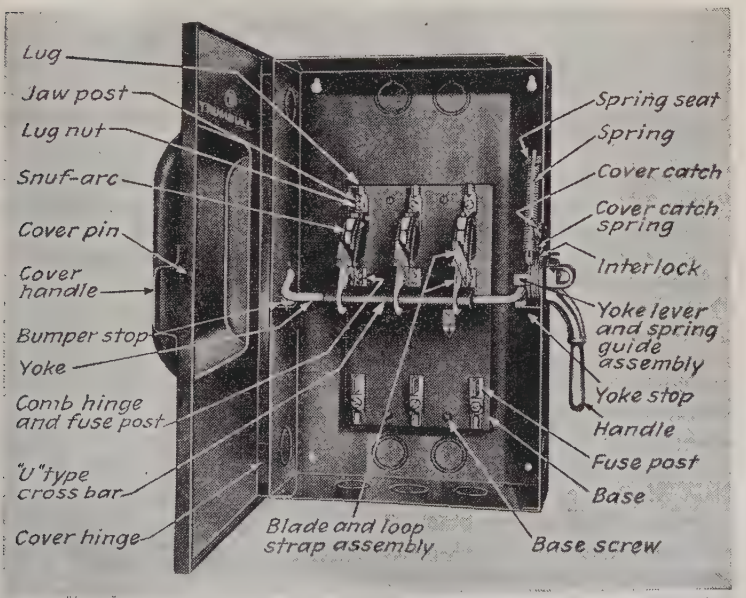


FIG. 24.—Typical Class A, knife-blade-type safety-switch construction. (*Trumbull Electric Manufacturing Co.*)

Safety switches of certain types are so arranged that their doors cannot be opened when the switch is closed. Others possess this feature and the additional one that, when the switch and door are open, absolutely no live

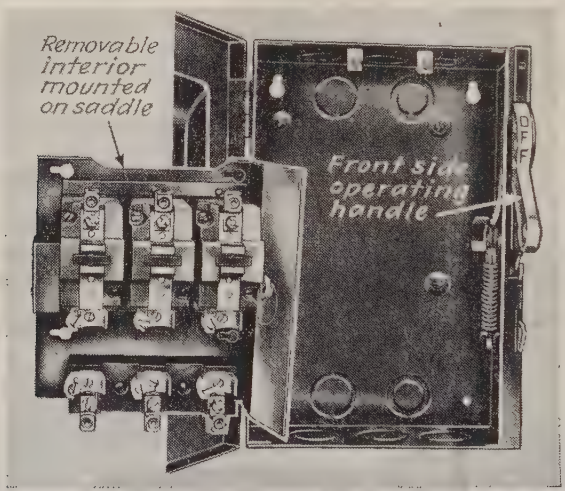


FIG. 25.—Safety switch of double-break, butt-contact (single-line) construction. Construction of switch-constants is shown in Fig. 6, II. (*Trumbull Electric Manufacturing Co.*)

metal parts are exposed. When the switches are maintained by skilled persons who appreciate the possible dangers, the refinements which are desirable for unskilled attendants are not necessary.

Safety switches are made in two-, three-, four-, and five-pole assemblies either fused or unfused and in single- or double-throw types. The three-, four-, and five-pole switches may be of the standard, solid-neutral, or switching-neutral type. Safety switches are made in Class A, C, and D types of construction. They may be obtained with or without quick-break mechanism. Many switches are constructed so as to give quick-make action in the closing of the switch as well as the quick-break action in opening. Typical construction of a Class A, knife-blade-type safety switch is shown in Fig. 24. Butt-contact design (Fig. 25) generally results

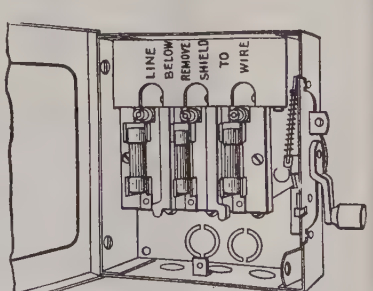


FIG. 26.—Rotary-type safety switch. (*Trumbull Electric Manufacturing Co.*)

in a more compact construction with smaller over-all dimensions. A very compact type of rotary knife-blade switch (Fig. 26) is made, however, in 30- and 60-amp. sizes.

Excessive heating at the fuse clips due to poor contact has often caused trouble in safety-switch installations. Many fused switches are provided with fuse clips of a positive-pressure type in order to safeguard against this difficulty. Two types of pressure-clamp fuse clips are shown in Fig. 27.

19. To make a contact between switch blade and jaws, considerable skill is required. After a switch is assembled, the jaws are first bent into correct position either by hand or by driving a block of wood against the distorted portion with a hammer. Then they are "ground in" with vaseline and fine (FF) pumice. Often the "fit" of a switch is reasonably good at the start, and merely working the blade in and out of the jaws by hand will grind them in. Before the grinding process is started, the portion of the blade that wipes the jaws should be daubed with the vaseline-and-pumice compound. The abrasive not only "grinds in the fit" but wears off the lacquer, which, if it remained, might be the cause of a bad contact. The surplus compound should be removed with a rag.

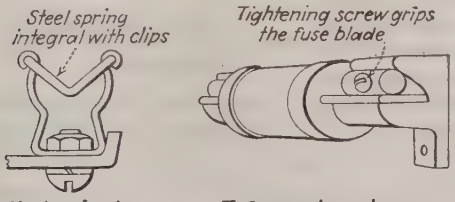


FIG. 27.—Positive-pressure-type fuse clips.

20. A test for good blade contact can be made by trying to insert a "feeler," which is a leaf of very thin steel, mica, or paper, between the jaws and blade at the corners and sides. About 0.001 to 0.004 in. is about the right thickness for a feeler. An excellent feeler can be made by hammering down to a knife-edge the edges of a strip of very thin metal possibly 4 in. long and $\frac{3}{4}$ in. wide. If the feeler slips in at any point, it is evident that the fit is poor at that point and the contact bad. Proper forming of the jaw will correct the difficulty. There have been cases where switches have been made to carry, without excessive temperature rise, currents 50 per cent greater than their normal ratings, by merely carefully fitting their jaws to their blades.

21. The standard sizes of general-purpose power switches are 30, 60, 100, 200, 400, 600, 800, and 1,200 amp. Safety switches are also made in 1,000- and 2,400-amp. sizes. Klamp-Tite switches are made in 400-, 600-, 800-, 1,000-, 1,200-, 1,600-, 2,000-, 3,000-, 4,000-, and 5,000-amp. sizes. Toggle switches are made in 300-, 500-, 600-, 800-, 1,000-, 1,200-, 1,600-, 2,000-, 2,500-, 3,000-, 4,000-, 5,000-, 6,000-, 8,000-, and 10,000-amp. sizes. The last two sizes are made only for d-c circuits.

22. Disconnecting or isolating switches are intended simply for disconnecting or isolating circuits from their source of power. They are not intended to be used for interrupting the current of the circuit and are only to be operated when the circuit has been opened by some other means. The principal application of these switches is for isolating equipment or parts of an electric circuit for inspection or repair. They are commonly used on circuits rated at more than 600 volts. They are made in a great variety of open knife-blade types to meet different requirements of both indoor and outdoor service. Since they are generally located out of arm's reach, they are provided with an eye on the free end of the blade for operation with a hook rod. A typical switch of this type is shown in Fig. 28. An enclosed safety industrial disconnecting switch is shown in Fig. 29. It provides a means of disconnecting the motor and its control equipment from the line for purposes of inspection and repairs. The switch illustrated is provided with jacks for the insertion of a test plug for the connection of meters to the circuit.

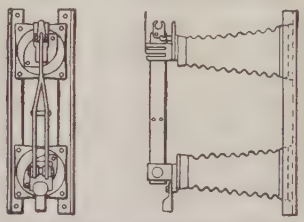
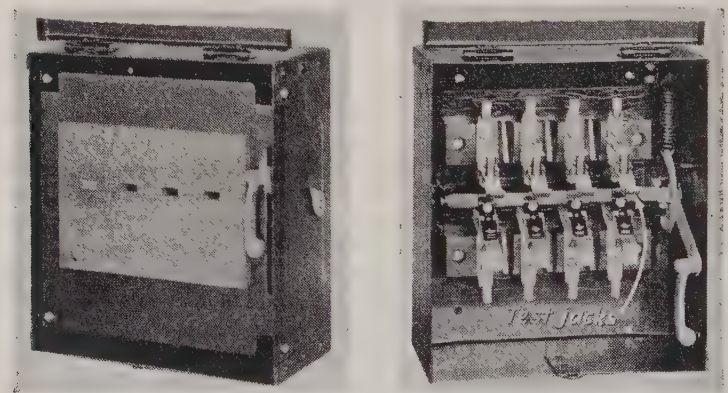


FIG. 28.—Indoor-type disconnecting switch. ("*Electric System Handbook.*")



I. Disconnecting switch, front cover open, exposing slots for jacks.

II. Disconnecting switch, front and slotted covers open, switch closed.

FIG. 29.—Disconnecting switch of industrial type with test jacks. (*General Electric Co.*)

23. Motor-circuit switches are used for the interruption of current in motor circuits. They are rated in horsepower and must be capable of interrupting at their rated voltage the maximum operating overload current of a motor of the same horsepower as the switch rating. The maxi-

mum operating overload current is taken as six times the rated full-load motor current for a-c motors, and four times the rated full-load motor current for d-c motors. Motor circuit switches are of the same construction as the general-purpose safety switches discussed in Sec. **18.** Most manufacturers employ the same switch for both classes of service. The switch is rated in amperes for general use and is given a horsepower rating for motor-circuit application.

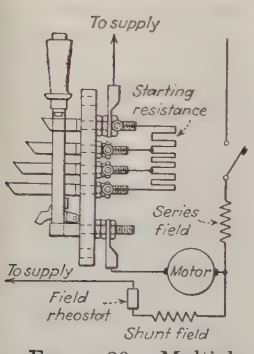
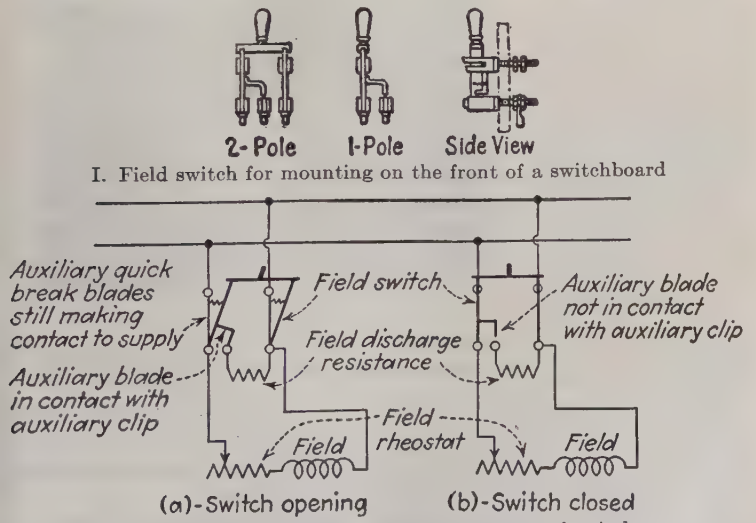


FIG. 30.—Multiple-contact open knife-blade switch for motor starting. ("*Electric System Handbook.*")

24. Motor-starting switches are employed for the starting of motors which may be started directly across-the-line. Standard motor-circuit switches may be used for this purpose, but it is generally better practice to employ a switch designed specifically for starting duty. They are made in manual and magnetic types. These motor-starting switches generally are provided with some form of motor-overload protective device. For a discussion of motor-starting switches refer to across-the-line starting equipment in Div. 5. When the control of a d-c motor is mounted on a switchboard, a multiple-contact, open knife switch (Fig. 30) is frequently employed for cutting out the starting resistance.



I. Field switch for mounting on the front of a switchboard

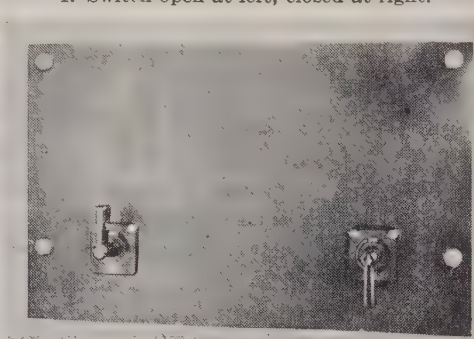
II. Schematic diagram showing functioning of switch.

FIG. 31.—Field switch.

These switches may be provided with a ratchet device on the hand lever so that the switch cannot be moved too rapidly from step to step.

25. Field switches are used for the interruption of the field current of generators and synchronous motors. These switches (Fig. 31) are provided with an auxiliary contact, an extra blade attached to one of the main blades, and auxiliary quick-break blades attached to each main blade. In operating the switch for disconnecting the field from its source, the auxiliary quick-break blades do not break contact with their jaws until after the short auxiliary blade has made contact with the extra jaws. Thus the field circuit is shorted through the discharge resistance before the circuit is disconnected from its source. Since the field circuit is highly inductive, if the circuit were suddenly broken a high induced voltage would be produced which might puncture the insulation of the field coils. The field switch of Fig. 31 is for mounting on the front of the switchboard or panel.

I. Switch open at left, closed at right.



II. Operating handles.

FIG. 32.—Field switch for mounting on the rear of a switchboard with front operating handle.

A preferable arrangement is to employ a switch mounted on the rear of the board as shown in Fig. 32. Electrically operated field switches can be obtained which allow the field switch to be mounted near its machine, while its operation is controlled from the switchboard.

26. Service or Entrance Switches.—The service equipment to a building consists of the necessary circuit breaker or switch and fuses and their accessories, which are located near the point of entrance of the supply conductors. It constitutes the main control and means of cutoff for the supply to that building. In large industrial plants comprising several

buildings, the service equipment for each building will generally consist simply of a fused safety switch or an industrial circuit breaker. For single buildings supplied directly from the utility's lines, the service equip-

FIG. 33.—Installation of service switches connected with conduit to separate meter trough. (*Trumbull Electric Manufacturing Co.*)

ment must include a switch, fuses, and a meter, or a circuit breaker and a meter. The meter is furnished by the utility, but the rest of the equipment must generally be supplied by the consumer. Service or entrance switches are ones specifically designed to meet these entrance conditions so that the meter and fused switch may be mounted in a convenient, neat, and compact manner. The top end of most of the switch boxes is provided with knockouts for conduit connection or twistouts for accommodating standard meter trims (Fig. 35). This allows the box either to be connected by means of conduit to a separate meter trough (Fig. 33) or to have the meter mounted directly on top of the switch box (Fig. 34).

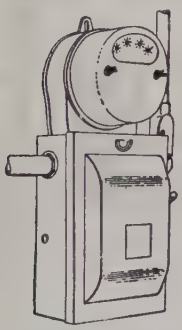


FIG. 34.—Installation of meter-service switch. (*Trumbull Electric Manufacturing Co.*)

27. Service or entrance switches are made in a great variety of types in order to meet the desired sequence between meter, switch, and fuses (refer to Div. 9) and the other requirements of individual utility companies. It has been impossible to introduce any standardization into the types of service switch owing to the divergence of opinion among the utility representatives Some of these switches simply include the entrance switching device (Figs. 33; 34; 37, I; and 40) and overload protection for the service. Others have in addition a switching device and overload protection for an electric-range circuit. Still others combine the service-entrance equipment with overload protection for branch circuits and frequently are called load and service centers (Figs.

36; 37, II; and 38). Types are available which include test links mounted on the main switch base so that the utility may test the meters without disconnecting the load and interrupting the customer's service. In some types the main fuses are accessible to the customer (Figs. 36, 37, and 40) while in others they may be sealed by the power company so that they are not accessible to the customer. (Figs. 33, 34 and 38.)

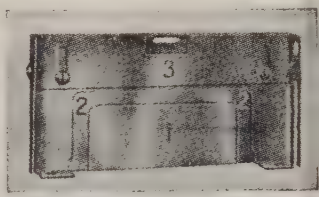
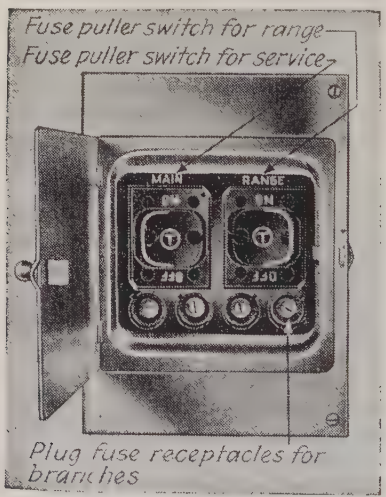
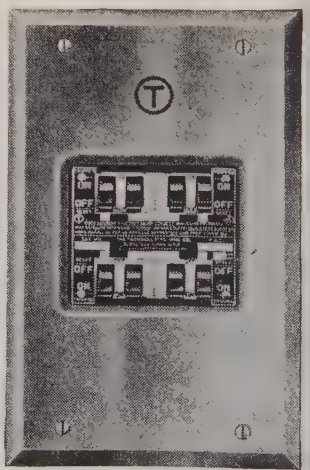


FIG. 35.—End wall of entrance switch box showing twistouts for accommodation of meter trims. (*Trumbull Electric Manufacturing Co.*)

Service switches may be divided broadly into three types, depending upon the type of main switching device: fuse-puller switches (Figs. 36, I, and 40, II), circuit breakers (Fig. 36, II), and the standard type of safety switch (Figs. 33, 34, 37, 38, and 40, I). A description of fuse-puller switches is given in Sec. **97.** When the main switching device is a circuit breaker, the equipment generally is of the



I. Fuse-puller switch type.



II. Circuit-breaker type. May include breakers for main, range, and branch circuits.

FIG. 36.—Meter-service switches and load centers. (*Trumbull Electric Manufacturing Co.*)

load-center type with each branch provided with a circuit breaker. This type has the advantage that it provides a means of switching as well as overload protection for each branch. The other types of load center provide only overload protection for the branches with no means of switching.

28. The latest development in service-entrance equipment is the detachable, socket type of meter. The meter is provided with prongs that fit into clips or jaws provided in a meter-mounting trough. Some of these troughs are wired on the job, and others are factory wired by the manufacturer. They are made in indoor and outdoor weatherproof types. Examples of troughs and installations of this type are shown in Figs. 33 and 39.

29. Service switches are available in raintight enclosures so that the service-entrance equipment may be located on the outside of the building. Typical equipment is shown in Fig. 40.

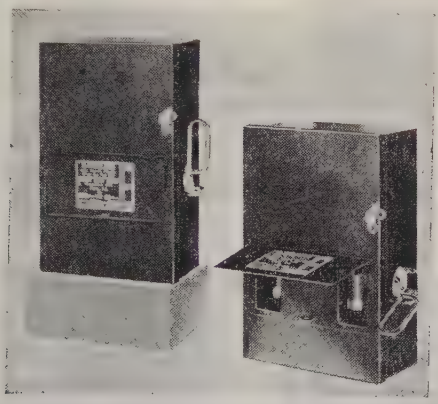
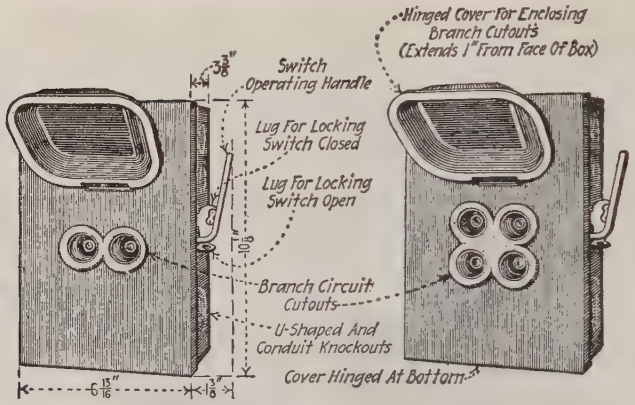


FIG. 37.—Service-entrance switch of the standard safety-switch type with accessible main-line fuses. (*Metropolitan Device Corp.*)

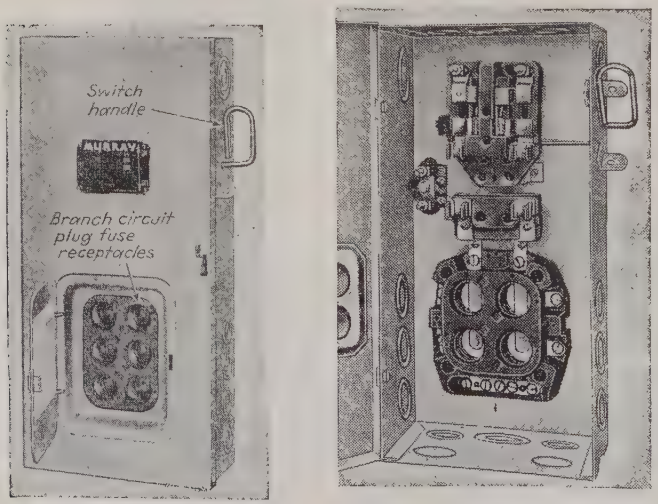
30. Wiring switches, as designated in this book, include all the relatively small switches that are employed in interior wiring installations for the control of branch circuits and individual lamps or appliances. Except for mercury switches, the switching mechanism consists of a snap action operated by one of the methods given in Sec. **9.** Wiring switches are made in many types in order to meet the requirements for different conditions of mounting.

The **flush type** of switch (Figs. 41 and 42) consists of a switch mechanism mounted in a porcelain or composition molded case with the complete unit designed to be mounted inside a switch box, outlet box, or conduit fitting so that the operating handle or button is the only portion of the switch which extends beyond the cover of the box or conduit fitting. The contacts may be of the knife-blade or mercury type (Sec. **7**). Those with knife blades are available with tumbler, push-button, or locking types of operating mechanisms. Mercury switches are almost completely silent in operation, making practically no noise on the make or break. They are used in installations where the click of a switch might



I. Arranged to serve two branch circuits. II. Arranged to serve four branch circuits.

a. Universal service-entrance switch and load center. (*The Johns-Pratt Co.*)

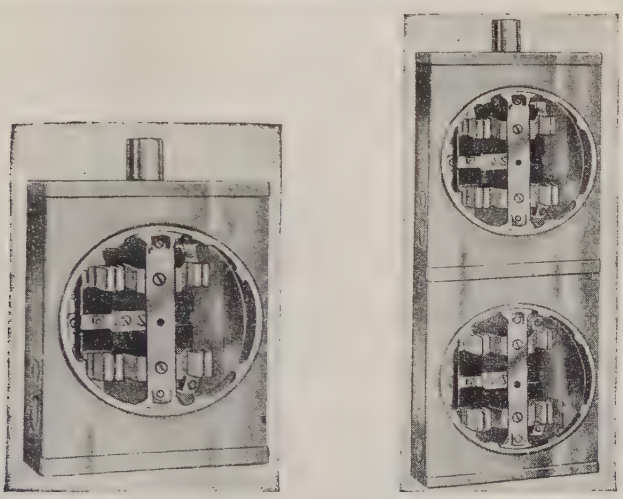


I. Door closed. II. Door open.

b. Service entrance-switch and load center. (*Metropolitan Device Corp.*)

FIG. 38.—Service-entrance switches and load centers of the standard safety-switch type with sealable main-line fuses. Main-line fuses are inside box. Cover may be locked or sealed.

prove disturbing, such as in hospitals, nurseries, etc. Locking switches do not have a protruding operating handle but are operated by a key inserted in a slot in the face of the switch mounting.



I. Trough for single meter. II. Meter trough.

FIG. 39.—Meter troughs for detachable socket-type meters. (*Trumbull Electric Manufacturing Co.*)

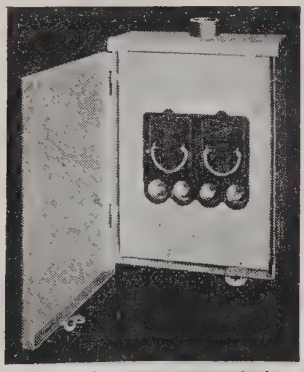


FIG. 40.—Outdoor service-entrance switch and load center.

Flush-mounted switches may be classified into three subtypes depending upon the physical size and mounting of the switch. The **standard line** of switches (Figs. 41 and 42) is made with more generous proportions and is the most rugged of the three types. It should be used for heavy-

duty installations and where frequent operation is required. The overall dimensions range from 1 to 2 in. in depth, $1\frac{7}{16}$ to 2 in. in width, and from $2\frac{3}{8}$ to $3\frac{3}{16}$ in. in length. Most of these switches are supplied with

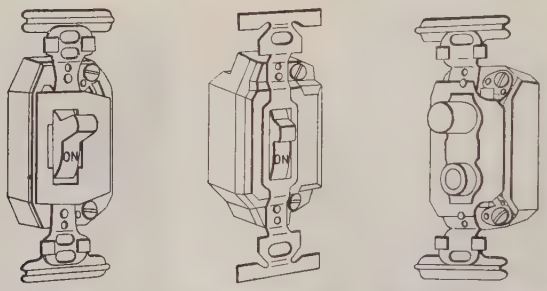


FIG. 41.—Standard line of flush wiring switches. (*Pass & Seymour, Inc.*)

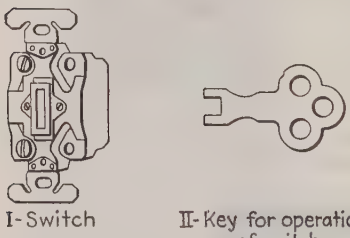


FIG. 42.—Locking type of tumbler flush switch, standard line construction.

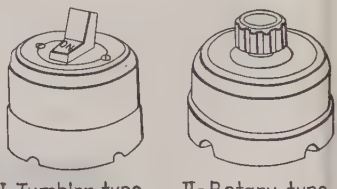


FIG. 43.—Surface-wiring switches. (*Pass & Seymour, Inc.*)

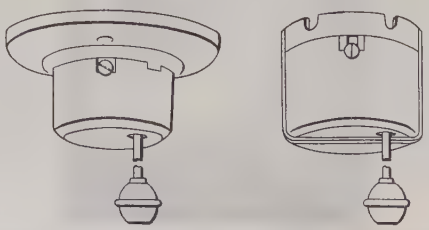


FIG. 44.—Ceiling types of pull rotary switches.

two sets of supporting screw holes, spaced from center to center $3\frac{9}{32}$ and $2\frac{3}{8}$ in., respectively. They are made in sizes up to 30 amp. capacity. Switches of standard-line dimensions are made in regular tumbler, push-button, locking, and mercury types.

The **interchangeable line** of switches (Fig. 45) is constructed in a much more compact manner with less generous proportions. As many as three of these switches may be installed in the same space required for a single standard-line switch. They should not be used for heavy-duty installations or where very frequent operation is required. The largest size switch made in this line is 10 amp. Three switches or a combination of three units of switches, receptacles, and pilot lights may be assembled

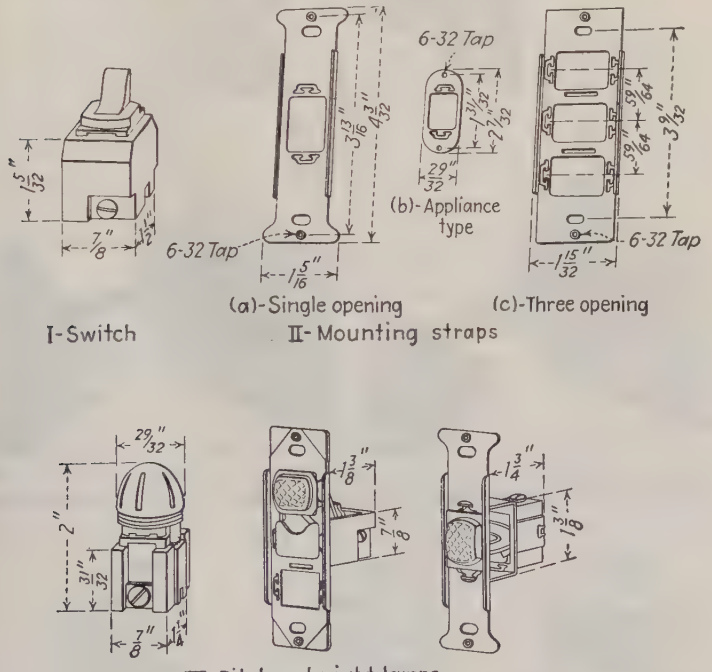


FIG. 45.—Parts for interchangeable line of surface switches. (*Pass & Seymour, Inc.*)

on a single supporting strap yoke and mounted in a single gang outlet box or switch box (see Figs. 45 and 47). These switches are made in tumbler and locking types with knife-blade contacts.

The **combination line** of switches (Fig. 48) is similar, in general construction, generosity of proportions of parts, and service for which they are suited, to the interchangeable line. It consists of combination assemblies of switches, switch and receptacles, switches and pilot light, or switch, pilot light, and receptacle mounted in one molded composition body. A combination body can be mounted in a single gang box.

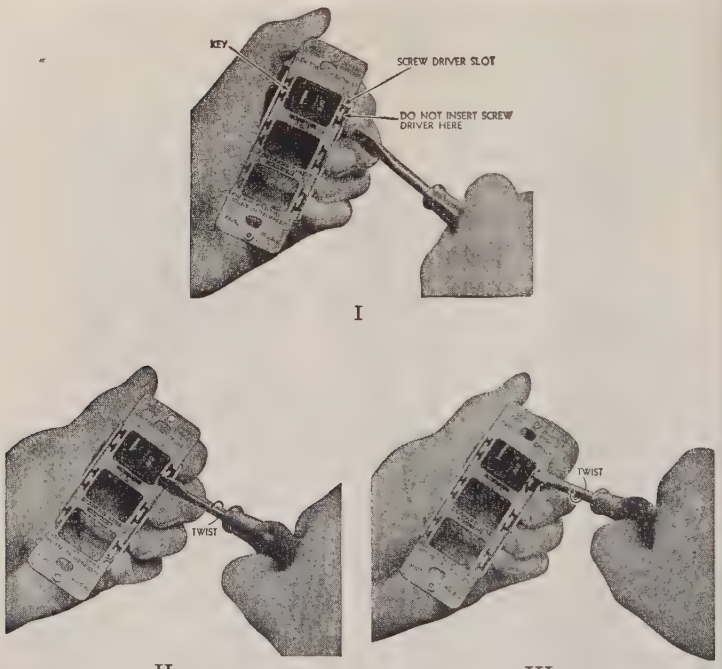


FIG. 46.—Method of assembling units and strap. (*Pass & Seymour Inc.*)

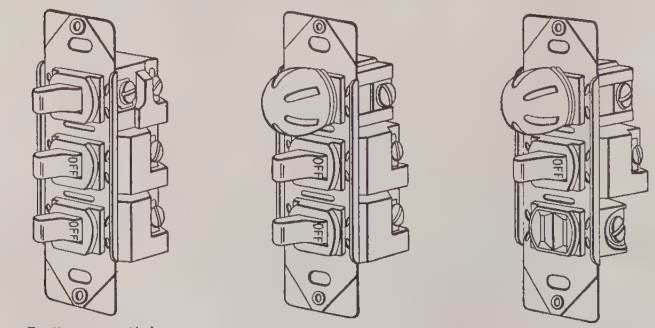
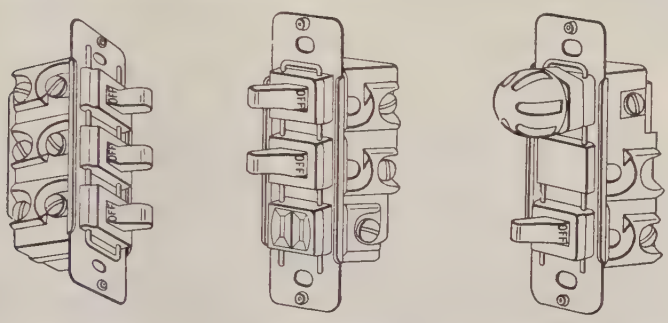


FIG. 47.—Typical assemblies of interchangeable wiring devices. (*Pass & Seymour, Inc.*)

Surface switches (Figs. 43 and 44) are designed for mounting on the surface of a wall, ceiling, or box so that all or practically all the switch body extends beyond the surface upon which it is mounted. The contacts are of the knife-blade type operated by tumbler or rotary action.

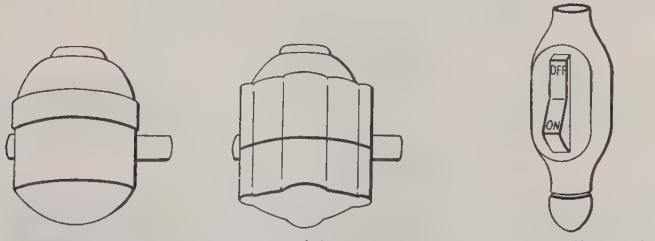


I- Three switch II- Two switches with one receptacle III- Switch and lamp with one blank

FIG. 48.—Combination line of flush switches and devices. (*General Electric Co.*)

Special heavy-duty tumbler switches for mounting in cabinets or boxes are made in double- and three-pole types up to 60 amp. capacity for 250 volts.

Pendant switches (Fig. 49) are used for the control of lamps or other devices which are mounted overhead out of reach from persons standing on the floor. They are supported at the end of a pendant two-conductor cord, and their operation opens and closes the circuit of the cord.



I- Brass shell (General Electric Co.) II- Porcelain shell III- Bakelite shell (Pass & Seymour, Inc.)

FIG. 49.—Pendant switches.

Through-cord switches (Fig. 50) are designed to be inserted in a portable cord for control of the cord circuit.

Door switches (Fig. 51) are for the purpose of controlling circuits through the opening and closing of doors. They are mounted in boxes

located in the doorjamb. Two types are available, one constructed so that the switch is closed when the door is open and the other so that the switch is closed when the door is closed.

FIG. 50.—Through-cord switch. (*Pass & Seymour, Inc.*)

FIG. 51.—Door switch. (*General Electric Co.*)

Canopy switches (Fig. 52) are small compact switches for mounting in the canopies of lighting fixtures for the control of the lamps direct

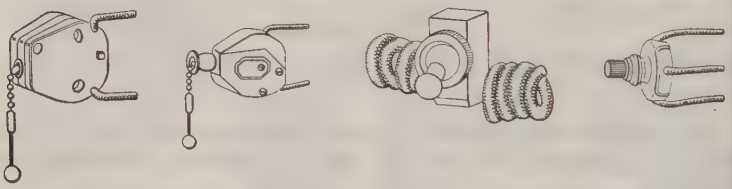


FIG. 52.—Various types of canopy switches. (*General Electric Co.*)

at the fixture. They may be obtained in pull-chain or toggle-switch types.

Appliance switches are made in a variety of types for mounting in the appliance enclosure.

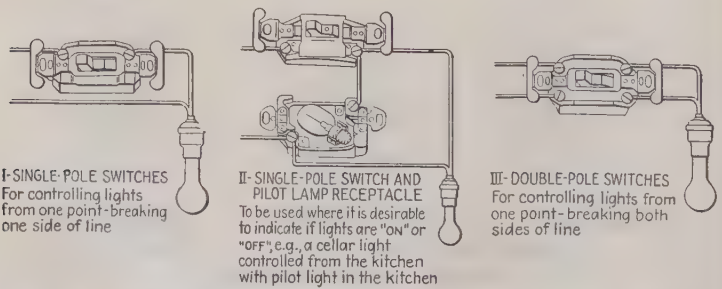


FIG. 53.—Connections and functions of single- and double-pole switches.

Rotary surface switches may be obtained mounted in special enclosures to meet the conditions of special exposures such as weather, water, or explosive atmospheres.

31. Wiring switches are available in different types in order to perform different functions in the wiring system. The regular switches designated simply as **single pole** or **double pole** are for the general-purpose use of opening and closing circuits for control of lamps or other devices from a single point. The single-pole switches (Fig. 53, I and II) break the circuit of only one side of the line, while the double-pole switch (Fig. 53, III) breaks the circuit of both sides.

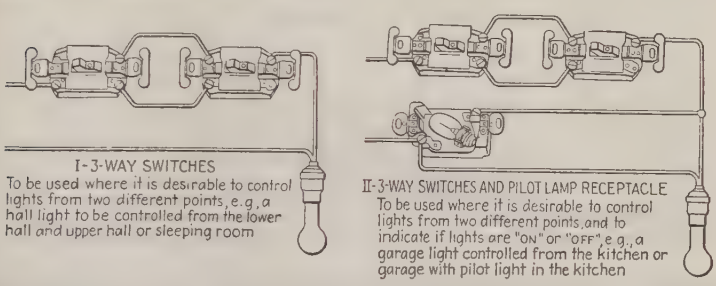


FIG. 54.—Connections and functions of three-way switches.

Three-way switches are used where it is desired to control lights from two different points, such as a hall light to be controlled from the lower hall and the upper hall. The lights may be turned on or off from either position. Three-way switches when properly connected (see Sec. **33**) break the circuit of only one side of the line; they do not isolate the circuit from the supply. The method of controlling a lamp from two positions with two three-way switches is shown in Fig. 54.

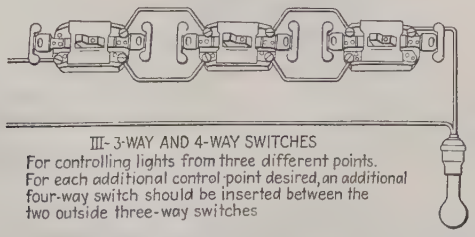


FIG. 55.—Connections and functions of three-way and four-way switches.

Four-way switches in conjunction with two three-way switches are used where it is desired to control lights from three or more different points. Two three-way switches are required with as many four-way switches connected between the two three-way ones as there are points of control in excess of two. Thus to control lights from four different points requires two three-way switches with two four-way switches connected between them. The method of control from three different locations is

shown in Fig. 55. Four-way switches when properly connected break the circuit of only one side of the line.

Three- and four-pole switches are available in tumbler and rotary types for a limited number of applications for control of circuits with three or four wires.

Multiple-circuit or electrolier switches are used for the control of lights in multiple-lamp fixtures so that one lamp or set of lamps may be turned

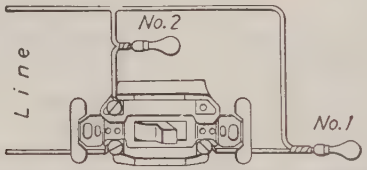


FIG. 56.—Two-circuit electrolier switch.

1st position—circuit No. 1
2d position—circuit off
3d position—circuits Nos. 1 and 2
4th position—all circuits off

on alone or in combination with other lamps. The method of control is shown in Figs. 56 and 57. These switches break the circuit of only one side of the line.

Momentary-contact switches are used where it is desired to close or open a circuit for only a short length of time. The switch is provided

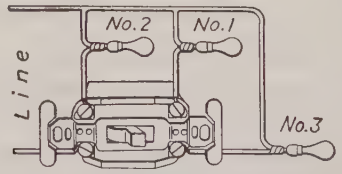


FIG. 57.—Three-circuit electrolier switch.

1st position—circuit No. 1
2d position—circuit off
3d position—circuits Nos. 1 and 2
4th position—circuits off
5th position—circuits Nos. 1, 2, and 3
6th position—all circuits off

with a spring so that it will return to its original position as soon as the handle or button is released. They are available in standard-line tumbler and push-button types of flush switches and in push-button surface types.

Heater switches are designed for the control of circuits for electric ranges and electric heating devices. They are made in single- and double-pole types for control of single, double, or triple heats.

32. Common Available Wiring Switches

Type of mounting, construction, and voltage	Current capacities regularly available for switches of following function:										
	Single pole	Double pole	Three pole	Four pole	Three way	Four way	Electrolier	Momentary contact	Heater, single heat	Heater, double heat	Heater, triple heat
1. Flush, standard line:											
a. Tumbler, knife blade, 125 volts (with regular operating handle or lock type).	10*T* 20*T* 30*T*	10*T* 20*T* 30*T*	.. .. ..	.. .. ..	10*T* 20*T* 30*T*	5*T* 10*T* 20*T*	....	10			
b. Tumbler, knife blade, 250 volts (with regular operating handle or lock type).	5 10 20 30	10 20 30	.. ..	.. ..	5 10 20 30	2 5 10	....	5			
c. Push button, 125 volts	10	10	..	..	10	5	10	10			
d. Push button, 250 volts	5	10	..	..	5	2	5	5			
e. Tumbler, mercury contact, 125 volts.	5*T* 10*T*	5*T*	..	..	5*T*	5*T*					
f. Tumbler, mercury contact, 250 volts.	5	5	..	..	5	5					
2. Flush, interchangeable line:											
a. Tumbler, knife blade, 125 volts (with regular operating handle or lock type)	10*T*	10*T*	..	..	10*T*	5*T*	....	10			
b. Tumbler, knife blade, 250 volts (with regular operating handle)	5	10	..	..	5	2	....	5			
3. Flush, combination line:											
a. Tumbler, knife blade, 125 volts (with regular operating handle)	10*T*	10*T*	..	..	10*T*	5*T*					
b. Tumbler, knife blade, 250 volts (with regular operating handle)	5	10	..	..	5	2					
4. Surface, tumbler general purpose:											
a. 125 volts	5 6 10	5 10 20	.. ..	.. ..	5 10	5					
b. 250 volts	3 5	10 20	.. ..	.. ..	2 3 5	2					
5. Surface, rotary:											
a. 125 volts	5 6 10	.... 10 20	.. 20 ..	.. 20 ..	.... 3 10	.... 5 10	.... 5	.. .. ..	.. 30 50	.... 15	15 30 50
b. 250 volts	3 5	5 10 20	.. 20 ..	.. 20 ..	1 3 5	.... 2	.... 2	.. .. ..	10 50 ..	7½	7½ 10 30
c. 600 volts	3 10	3 10	.. ..	.. ..	3 5						

Common Available Wiring Switches (*Continued*)

Type of mounting, construction, and voltage	Current capacities regularly available for switches of following function:											
	Single pole	Double pole	Three pole	Four pole	Three way	Four way	Electrolier	Momentary contact	Heater, single heat	Heater, double heat	Heater, triple heat
6. Surface, momentary contact, push button:											
a. 250 volts	.....	....	..	..	....	....	5				
b. 500 volts	.....	....	..	..	....	....	2.5				
7. Heavy-duty tumbler for mounting in cabinets or boxes:											
a. 125 volts	30	30 60	60								
b. 250 volts	...	20 30	30								
8. Pendant:											
a. 125 volts	6 10										
b. 250 volts	3 5										
9. Through cord:											
a. 125 volts	10										
b. 250 volts	5										
10. Door:											
a. 125 volts	3										
b. 250 volts	6										
11. Canopy:											
a. 125 volts	3 6										
b. 250 volts	1 3										

NOTE.—The *T* after a current rating on a switch indicates that the switch will satisfactorily carry Type C incandescent lamp loads of that value of current and that the switch is in accordance with the Underwriters *T* rating.

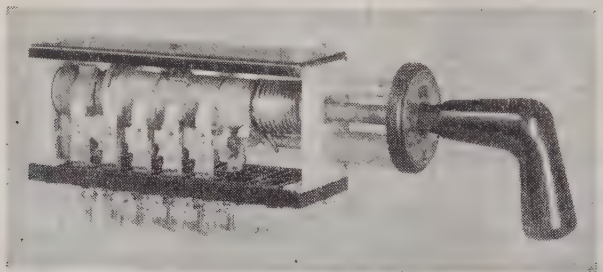


FIG. 58.—Rotary type of control switch, with cover removed. (*Westinghouse Electric & Manufacturing Co.*)

33. Caution should be exercised in connecting three-way and four-way switches, since it is possible to connect these switches with both sides of the circuit connected to each switch. This is an improper connection

which should never be used. The switch is not designed for this purpose and in case of failure of the switch mechanism a short circuit may result. The right and wrong methods of connections are shown in Figs. 63 and 64. Refer to Sec. **38** for additional information on connection of these switches.

34. Control switches are used for controlling from a switchboard the operation of electrically operated equipment such as switches, circuit

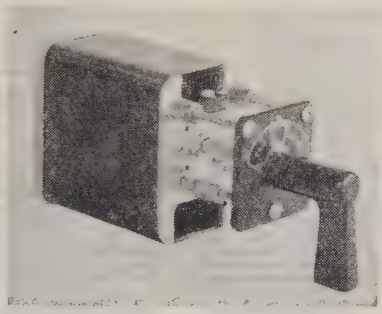


FIG. 59.—Control switch. (*General Electric Co.*)

breakers, rheostats, prime-mover governors, etc. They are generally of the drum or rotary type. Two representative control switches are shown in Figs. 58 and 59. Pilot lamps are generally used in connection with control switches in order to indicate to the operator the position of the controlled equipment.

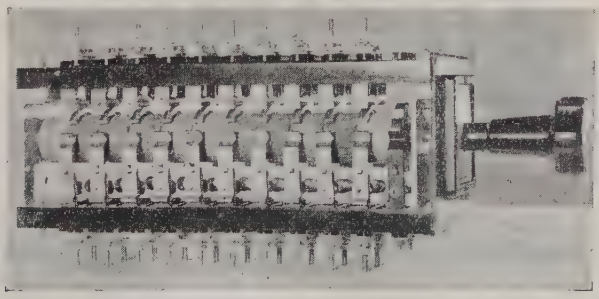


FIG. 60.—Rotary type of instrument switch with cover removed. (*Westinghouse Electric & Manufacturing Co.*)

35. Instrument switches are employed for changing the connections of meters from one circuit to another. The most common type is of rotary construction as shown in Fig. 60. The plug-and-receptable type of switch is also employed for connecting a common voltmeter, ammeter, or synchroscope to various circuits. One plug is used for each set of common receptacles so that it is impossible to make cross connections.

Examples of plug-and-receptable equipment are shown in Figs. 61 and 62.

36. Various miscellaneous types of switches are available for special applications. Knife-blade switches of reduced dimensions are available for low-voltage circuits such as telephone, signaling, and battery circuits.

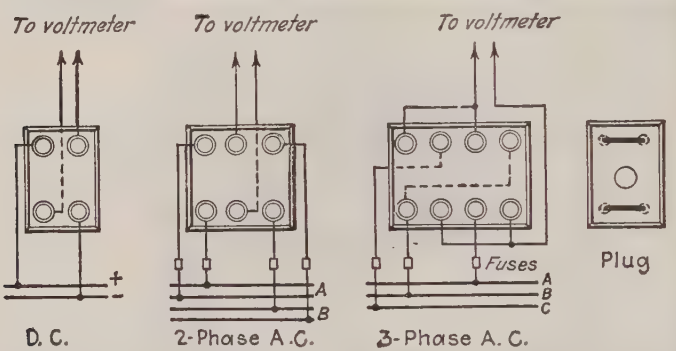


FIG. 61.—Voltmeter receptacles and plug. ("*Electric System Handbook.*")

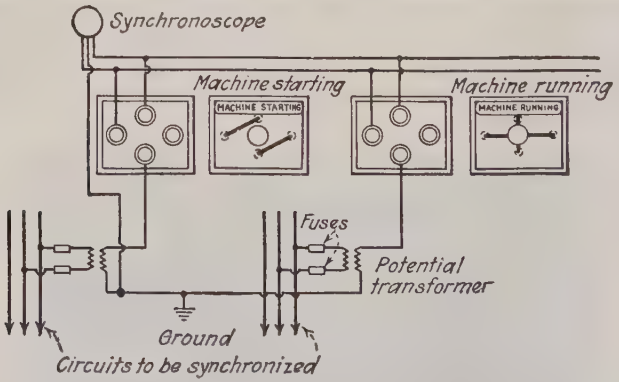


FIG. 62.—Synchronizing plugs and receptacles. ("*Electric System Handbook.*")

INSTALLATION OF SWITCHES

37. A switch or circuit breaker must not be installed so that it will disconnect a grounded conductor of a circuit unless the switching mechanism simultaneously disconnects all wires of the circuit or is so arranged that the grounded conductor cannot be disconnected until the ungrounded conductor or conductors have first been disconnected.

38. Three-way and four-way switches are in reality single-pole switches and therefore must be installed so that all switching is done only in the

ungrounded conductor. When the wiring for these switches is enclosed in a metal enclosure, the wiring must be so installed that at every point the same enclosure includes wires of both polarities. The correct and incorrect methods of wiring such switches are illustrated in Figs. 63, 64, and 65. Refer to Secs. **31** and **33** for additional information on three- and four-way switches.

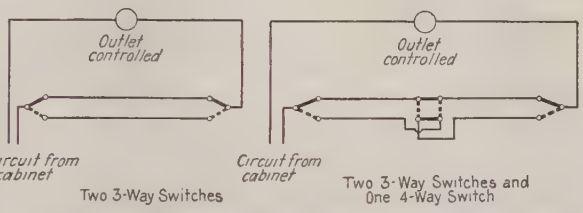


FIG. 63.—Right method of connecting three-way and four-way switches. ("*National Electrical Code Handbook.*")

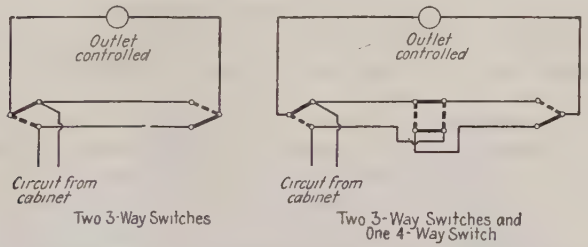


FIG. 64.—Wrong method of connecting three-way and four-way switches. ("*National Electrical Code Handbook.*")

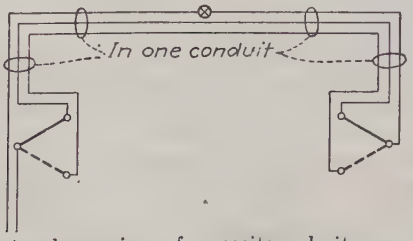


FIG. 65.—Illustrating how wires of opposite polarity must be enclosed in same conduit in the wiring of three-way switches.

39. Position of Mounting.—Single-throw knife switches should be so mounted that gravity will tend to open and not to close them (Figs. 66 and 67). Double-throw switches may be mounted so that the throw is either vertical or horizontal. If mounted with the throw vertical, the switch must be provided with a locking device which will hold the blades in the open position when so set.

40. In connecting knife switches in a circuit the switch should be wired so that the blades will be dead when the switch is open.

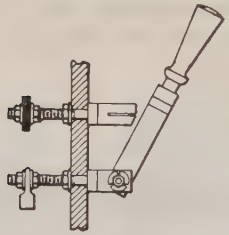


FIG. 66.—A single-throw switch mounted vertically so that gravity will not tend to close it. ("*National Electrical Code Handbook.*")

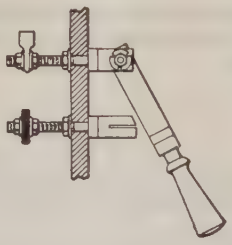


FIG. 67.—Wrong method of mounting a single-throw switch. In this position gravity tends to close the switch.

The National Electrical code will allow a switch to be connected so that the blades are alive when the switch is open, provided that it is impracticable to connect it in the other manner. A fused switch should

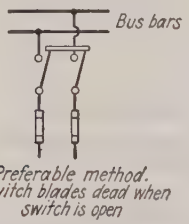


FIG. 68.—Preferable method of connecting a knife switch. ("*National Electrical Code Handbook.*")

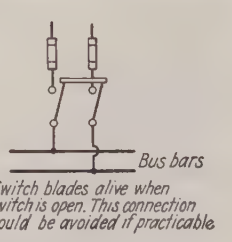


FIG. 69.—Less desirable method of connecting a knife switch. ("*National Electrical Code Handbook.*")

always be wired so that the fuses will be dead when the switch is open (Figs. 68 and 69).

PROTECTIVE DEVICES

41. Various forms of protective devices are employed for protecting electrical circuits and equipment from injury under abnormal conditions. These devices may be classified as follows according to the type of protection which they provide.

1. Overload protection.
2. Underload protection.
3. Undervoltage protection.

4. Overvoltage protection.
5. Reverse-current or power protection.
6. Reverse phase rotation.
7. Lightning and surge protection.

42. Relays and Releases.—Protection for the various types of abnormal conditions is in most cases provided by means of relays or release devices which actuate the opening of circuit breakers or switches. If protection is afforded by means of a simple release device, the abnormal condition causes the functioning of the release device, which acts directly upon a holding catch of the switch or breaker mechanism. With relay protection the abnormal condition causes the functioning of the relay, which opens or closes an auxiliary electric circuit, which in turn trips the switch or breaker mechanism.

Release devices may be of the thermal or magnetic types. Thermal releases can be employed only for overload protection. Their operation depends upon the deflection of a bimetallic element as it is heated by the current of the circuit. Magnetic releases consist of a solenoid acting upon an iron plunger or armature. For current protection the coil of the solenoid is connected in series with the circuit, while for voltage protection the coil is connected across the circuit which is to be protected.

Relays may be of the thermal, magnetic, or induction types. The principles of operation of the thermal and magnetic types are the same as those for releases of the same type. Induction relays operate upon the same general principle as induction motors and, therefore, are applicable only to a-c systems.

43. Time Characteristics.—Relays and release devices may be classified according to the time that will elapse between the occurrence of the abnormal condition and the opening of the circuit. There are three general types: the instantaneous or high speed, the definite time, and the inverse time. In the instantaneous type, time delay is purposely omitted from its action so that the circuit is opened almost instantaneously upon the occurrence of the abnormal condition for which the release or relay is set. A definite time relay or release is purposely so designed that there is a definite time delay in its action. The abnormal condition must exist for a definite time before the device will function to open the circuit. The length of time of the disturbance required to cause the device to function is independent of the magnitude of the disturbance. An inverse-time relay or release is purposely so designed that there is a time delay in its action. The length of time of the disturbance required to cause the device to function is dependent upon the magnitude of the disturbance. The greater the magnitude of the disturbance the quicker will the device function to open the circuit. All thermal relays and releases, owing to the principle of their construction, provide inverse-time protection.

44. Overload protective devices are used in order to protect wires, wiring fittings and devices, and apparatus against excessive currents.

The several types of overload protective devices may be divided into the following groups:

Means of Protection	For Protection of
1. Fuses.	
a. Link fuses	Circuits by special permission
b. Standard plug fuses	Circuits and apparatus
c. Standard cartridge fuses	Circuits and apparatus
d. Time-lag fuses	Circuits and apparatus
e. High-voltage fuses	Circuits and apparatus
2. Thermal cutouts	Motors
3. Circuit breakers actuated by:	
a. Thermal overload release device	Circuits
b. Thermal relay	Circuits
c. Magnetic release device	Circuits and apparatus
d. Magnetic relay	Circuits and apparatus
e. Combined thermal and magnetic release	Circuits and apparatus
f. Induction relays	Circuits and apparatus
4. Manual switches actuated by thermal releases	Motors
5. Magnetic switches actuated by:	
a. Thermal relays	Motors
b. Magnetic relays	Motors

With fuses and thermal cutouts the circuit is opened, in case of overload, inside the device itself. These two overload protective devices must be capable, therefore, of interrupting the line current and of extinguishing the arc that is thus formed. Relays or overload release devices themselves do not interrupt the line current of the circuit which they are protecting. An overload release device, when operated by a current greater than that for which it is set, trips the holding catch of the switch mechanism and thus allows the switch mechanism to open. The current is interrupted by the switch mechanism and not by the overload release device. An overload relay instead of acting directly upon the holding catch of the switch mechanism opens an auxiliary circuit. This auxiliary circuit may be the operating coil of a magnetic switch or the shunt trip coil of a circuit breaker. As with the overload release devices, the relay does not interrupt the main-line current itself. The main circuit is opened by the contacts of the switch mechanism.

45. Fuses and circuit breakers are used for the overload protection of both circuits and apparatus. Thermal cutouts, thermal overload release devices, and thermal relays are used for the protection of motors against overloads. They should not be used for the protection of circuits unless they are specifically designed and approved for that purpose. Thermal overload protective devices have admirable characteristics for the protection of motors against overloads, but they should not be relied upon for protection against short circuits unless they are specifically designed and approved for that purpose. Unless so designed in the case of a short circuit there is danger of the excessive current destroying the thermal

element before it has actuated the switch mechanism, with the consequent failure of opening the circuit. Circuit breakers actuated by thermal overload release devices and designed for protection against short circuit have been developed and are widely used for the protection of circuits of small and medium current-carrying capacity. When thermal overload protective devices are employed for the protection of motors, fuses of the proper rating or circuit breakers with the proper setting should always be located at some point back in the line ahead of the thermal protective device.

46. Open link fuses (Fig. 70) consist of a wire or strip of easily melted material of such dimensions that it will melt at a definite rated current.

FIG. 70.—Stamped copper fuse link.

Link fuses are rated at 80 per cent of the maximum current that they will carry indefinitely. This allows for a 25 per cent overload of the fuse rating before the fuse will melt. The ends of the fuse wire or strip are fastened to copper terminals for convenience in connection in the circuit. Open link fuses have the disadvantage of disrupting violently, when a short circuit occurs, and may burn a person that is near. They blacken the panel that supports them. They are permitted by the Underwriters only when special permission is obtained, and when mounted on approved slate, marble, or composition bases. They are allowed by the National Electrical Code only in sizes rated at more than 600 amp. Except on switchboards they must be enclosed in iron or composition boxes or cabinets. When link fuses are employed, they must be so mounted that the clearance distances will not be less than the minimum values given in Table 47.

47. Minimum Clearance Distances in Inches for Mounting Link Fuses

Voltage rating	Current rating	Separation of metal parts of		Minimum break distance	Clearance between live parts and any metal of enclosing cabinet
		Opposite polarity	Like polarity		
125	600–1,500	1½	½	1¼	2
125–250	600–1,500	2¾	¾	2	2

48. Copper link fuses stamped from sheet copper are used for the protection of underground and aerial circuits. They have the disadvantage of becoming very hot before they rupture. At 75 per cent of their fusing capacities they often become so hot as to heat terminals or switches to which they are connected to undesirably high temperatures. Copper

fuses should always be enclosed in iron boxes. The General Electric Co. marks its copper fuses with the current that they will carry without undue heating and recommends them for the protection of underground circuits against dead short circuits only. Many thousands are in use in this service and for it give excellent satisfaction.

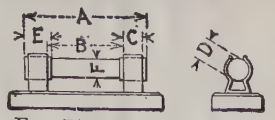
49. Diameters of Wires of Various Materials That Will Be Fused by a Current of a Given Strength

(Knox, "Electric Light Wiring"; derived from tables of W. H. Preece)

Current, amp.	Copper		Aluminum		German silver		Iron	
	Diam., in.	Nearest B. & S. gage	Diam., in.	Nearest B. & S. gage	Diam., in.	Nearest B. & S. gage	Diam., in.	Nearest B. & S. gage
1	0.0021	43	0.0026	41	0.0033	39	0.0047	37
2	0.0034	39	0.0041	38	0.0053	35	0.0074	33
3	0.0044	37	0.0054	35	0.0069	33	0.0097	30
4	0.0053	35	0.0065	34	0.0084	31	0.0117	29
5	0.0062	34	0.0076	32	0.0097	30	0.0136	27
10	0.0098	30	0.0120	28	0.0154	26	0.0216	24
15	0.0129	28	0.0158	26	0.0202	24	0.0283	21
20	0.0156	26	0.0191	24	0.0245	22	0.0343	19
25	0.0181	25	0.0222	23	0.0284	21	0.0398	18
30	0.0205	24	0.0250	22	0.0320	20	0.0450	17
35	0.0227	23	0.0277	21	0.0356	19	0.0498	16
40	0.0248	22	0.0303	20	0.0388	18	0.0545	15
45	0.0268	21	0.0328	20	0.0420	18	0.0589	15
50	0.0288	21	0.0352	19	0.0450	17	0.0632	14
60	0.0325	20	0.0397	18	0.0509	16	0.0714	13
70	0.0360	19	0.0440	17	0.0564	15	0.0791	12
80	0.0394	18	0.0481	16	0.0616	14	0.0864	12
90	0.0426	18	0.0520	16	0.0667	14	0.0935	11
100	0.0457	17	0.0558	15	0.0715	13	0.1003	10
120	0.0516	16	0.0630	14	0.0808	12	0.1133	9
140	0.0572	15	0.0698	14	0.0895	11	0.1255	8
160	0.0625	14	0.0763	13	0.0978	10	0.1372	7
180	0.0676	14	0.0826	12	0.1058	10	0.1484	7
200	0.0725	13	0.0886	11	0.1135	9	0.1592	6
225	0.0784	12	0.0958	10	0.1228	8	0.1722	5
250	0.0841	12	0.1028	10	0.1317	8	0.1848	5
275	0.0897	11	0.1095	9	0.1404	7	0.1969	4
300	0.0950	11	0.1161	9	0.1487	7	0.2086	4

50. Dimensions of National Electrical Code Standard Enclosed Fuses

Form I
(0 to 60 Amperes)
Cartridge Fuse-Ferrule Contact



Form II
(61 to 600 Amperes)
Cartridge Fuse Knife-Blade Contact

FIG. 71.—National Electrical Code standard fuses and holders.

Voltage	Rated capacity, amp.	A Length over terminals, in.	B Distance between contact clips, in.	C Width of contact clips, in.	D Diam. of ferrules or thickness of terminal blades, in.	E Min. length of ferrules or of terminal blades outside of tube, in.	F Diameter of tube, in.	G Width of terminal blades, in.
0–250 (Form I)	0–30	2	1	½	9/16	½	½	
	31–60	3	1¾	⅝	13/16	⅝	¾	
(Form II)	61–100	5⅞	4	⅞	⅛	1	1	¾
	101–200	7⅛	4½	1¼	3/16	1⅜	1½	1⅛
	201–400	8⅝	5	1¾	¼	1⅞	2	1⅝
	401–600	10⅜	6	2⅛	¼	2¼	2½	2
251–600 (Form I)	0–30	5	4	½	13/16	½	¾	
	31–60	5½	4¼	⅝	1 1/16	⅝	1	
(Form II)	61–100	7⅞	6	⅞	⅛	1	1¼	¾
	101–200	9⅝	7	1¼	3/16	1⅜	1¾	1⅛
	201–400	11⅝	8	1¾	¼	1⅞	2½	1⅝
	401–600	13⅜	9	2⅛	¼	2¼	3	2

51. A nonrenewable cartridge or enclosed fuse consists of a tube of vulcanized fiber, paper, or some similar material (Fig. 72) within which the fuse is mounted. The fuse terminals are connected to contact pieces at the ends of the tube. An insulating, porous powder resembling chalk surrounds the fuse and fills or nearly fills the tube. When the fuse blows, the powdered material disrupts the arc. Sometimes the fuse is surrounded by a small air chamber as shown in the illustration. The formation of an arc is prevented in a cartridge fuse; therefore fuses of this type are more reliable than those of any other. See Table 50 for standard dimensions.

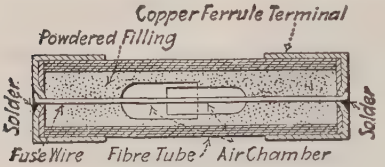


FIG. 72.—Cartridge-type enclosed nonrenewable fuse.

A blown-fuse indicator, made by the Signalite Fuse Co., can be quickly and easily installed without any special tools on any standard ferrule or knife-blade cartridge-fuse installation. The Signalite Indicator contains

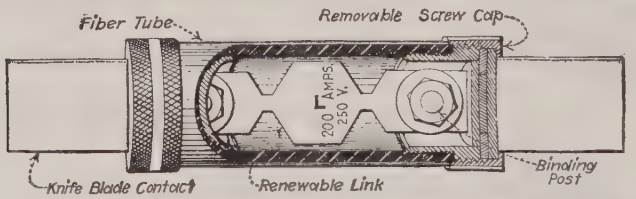


FIG. 73.—"Economy" 101- to 200-amp., knife-blade-contact renewable fuse.

a small neon tube which will light when the fuse on which it is installed blows. The indicator will outlast many fuse changes.

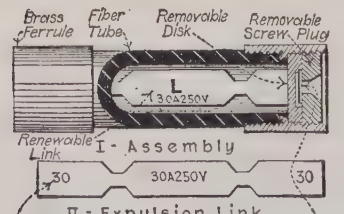


FIG. 74.—"Economy" 0- to 30-amp. ferrule-contact renewable fuse.

52. Renewable enclosed cartridge fuses (Figs. 73 and 74) of most makes have the approval of the Underwriters' Laboratories, which institution has issued standard specifications for their construction and testing. Hence, they may be installed in all localities where the National Electrical Code is effective. In renewable fuses the renewable link (Fig. 74 and *L* in the other illustrations) can be readily replaced when blown, inasmuch as the fuses can be taken apart easily with the hands and a screw driver for the insertion of a new link. Thereby, the fuse expense, in services wherein many fuses are blown, is greatly minimized. The

renewable fuses are made, according to capacity, in both the ferrule-contact (Fig. 74) and in the knife-blade-contact (Fig. 73) forms. Their external appearances and over-all dimensions are the same as for the nonrenewable fuses which are shown in Table 50. The laboratory tests to which renewable fuses are subjected by the Underwriters' Laboratories and which the fuses must satisfy before approval is accorded are practically the same as those for the corresponding nonrefillable fuses.

53. The ratings of National Electrical Code standard fuses are specified by the Underwriters' Laboratories in its publication "Underwriters' Laboratories Cartridge Enclosed Fuse Standard." The fuses should be so designed and constructed that they will carry indefinitely at an average room temperature of 75°F. (24°C.) a current 10 per cent greater and open the circuit at a current 25 per cent greater than the fuse rating. At a current 50 per cent greater than the fuse rating, the fuse, starting cold, must open the circuit, without throwing out melted metal or sufficient flame to ignite easily inflammable material, within the following times: 30 amp. or less, 30 sec.; 31 to 60 amp., 1 min.; 61 to 100 amp., 2 min.; 101 to 200 amp., 4 min.; 201 to 400 amp., 8 min.; 401 to 600 amp., 10 min.

54. Edison screw-base plug fuses (Fig. 75) consist of a wire or strip of fusible alloy mounted in a porcelain container. The container is fitted

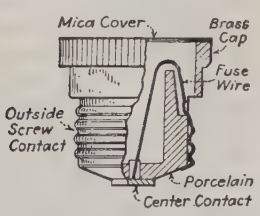


FIG. 75.—Edison plug fuse.

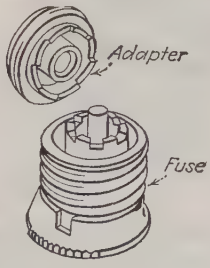


FIG. 76.—Tamper-resisting fuse. (*General Electric Co.*)

with a screw base corresponding with the standard medium lamp-base dimensions and threads. The top of the container is covered with a mica disk to make the fuse link visible. The standard sizes are 3, 6, 10, 12, 15, 20, 25, and 30 amp. Fuses of 15-amp. capacity or less are provided with a hexagonal window and those of greater capacity with a round window. Plug fuses shall be used only in circuits not exceeding 125 volts or circuits of a system having a grounded neutral and no conductor at more than 150 volts to ground. Plug fuses installed in residences should be of the time-delay type (see Sec. **56**).

The National Electrical Code recommends that all plug fuses and Edison screw-base plug-fuse casings (Sec. **55**) be of the tamper-resisting type. The tamper-resisting characteristics are generally obtained by means of a

special fuse construction and an adapter. A fuse and adapter of this type are shown in Fig. 76. The adapter is screwed on the base of the fuse and the two screwed as a unit into any standard Edison plug-fuse cutout or fuse holder. When the fuse is removed, the adapter remains secured in the cutout ready to receive the same or a new fuse. When the adapter is once inserted in the cutout, it prevents the use of an ordinary plug fuse. The Code rules require that the construction of fuses, fuse holder, and adapters be such that those of 0- to 15-amp. rating differ from those of 16- to 30-amp. rating so that fuses of the one group cannot be used interchangeably with those of the other group and so that the combination will be subject to tampering or bridging only with difficulty.

An indicating plug fuse (Fig. 76*A*) is made by the Signalite Fuse Co. This is a very convenient fuse, since a small neon lamp gives indication of a blown fuse and also since one casing contains six individual fuse elements. When one fuse element blows, the fuse does not have to be removed, but the top of the fuse casing can simply be revolved until the next fuse element is connected in the circuit. A small neon lamp is enclosed in the top of the fuse case so that the lamp is visible to the observer. The lamp is so connected that it moves with the fuse casing and is always connected across the fuse element, which is connected in the circuit. When the fuse element, which is connected in the circuit, is in operating condition, the neon lamp is not lighted. But, when the element blows, the neon lamp will light and give indication to the user of the location of the blown fuse.

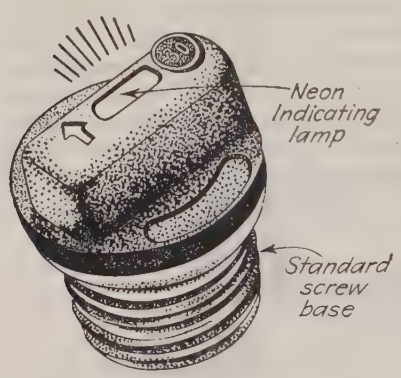


FIG. 76*A*.—Signalite fuse.

55. The use of an Edison screw-base plug-fuse casing with cartridge fuses is often advantageous. The construction and assembly of such a combination is shown in Fig. 77. Cartridge fuses installed with these plug casings are easy to remove.

56. Time-lag fuses are so constructed that they give a much greater time delay in the blowing of the fuse than do ordinary fuses. They are made in nonrenewable and renewable types. The nonrenewable type is available in the regular Edison screw-base type up to 30 amp. (Fig. 78), in tamperproof screw base up to 30 amp. (Fig. 79), and in the cartridge type up to 600 amp. The renewable types are available in sizes from 30 to 600 amp. The regular Edison screw-base type and the tamperproof-base type are identical except for the construction of the base. The

tamperproof-base type screws into an adapter. The complete assembly is then screwed into a regular Edison plug-fuse receptacle. Adapters are made in sizes of 15, 20, and 30 amp. The 15-amp. adapter will take any size fuse up to 15 amp. The 20-amp. adapter will take only a 20-amp. fuse, and the 30-amp- adapter will accommodate a 20, 25, or 30-amp. fuse.

The nonrenewable time-lag fuses consist of a fuse link to which a thermal cutout is added. The internal construction of the screw-base type is shown in Fig. 80. An overload causes the thermal cutout to heat up, and, if continued long enough, the solder in the thermal cutout softens and permits the spring to pull out the end of the fuse link, thus opening

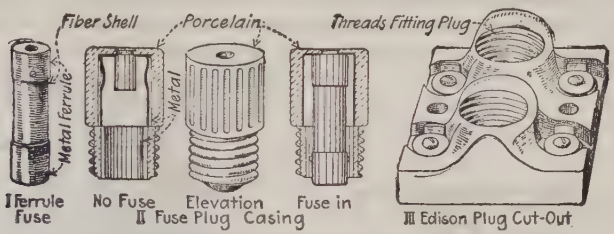


Fig. 77.—Edison plug cutout and Edison fuse plug casing.

Fig. 78.—Time-lag fuse with Edison screw base. Buss fusetron of the Bussmann Manufacturing Co.

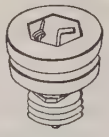


Fig. 79.—Time-lag fuse with tamperproof screw base. Buss fustat of the Bussmann Manufacturing Co.

the circuit. Because it takes some time to melt solder, even with a heavy current, the thermal cutout cannot open quickly, and the fuse link is heavy enough so it will not open quickly on motor-starting currents. Hence the time-lag fuse will not open on motor-starting currents that last only a short while. When a short circuit or an overload as high as 500 per cent occurs, the fuse link opens in exactly the same manner as an ordinary fuse.

A time-lag fuse designed especially for the protection of small motors is shown in Fig. 81. It is intended to be mounted directly on the motor. When the receptacle is properly installed, the heat from the motor windings is conducted to the thermal cutout in the time-lag fuse at point 1. Should the windings reach a prohibitive temperature, with just a normal

amount of current flowing, the time-lag fuse will open at point 1, and the motor will be shut down. The opening of the time-lag fuse under these conditions is primarily due to the heat of the motor windings, rather than to the current flowing through the fuse. Thus the motor is automatically protected against an excessive rise of the ambient temperature or failure of air circulation or any other condition causing excessive heating of the motor without a corresponding rise in the flow of current. If on the other hand the flow of current is so high that the insulation in the motor will be injured or destroyed before the mass of the motor is heated sufficiently to operate the time-lag fuse as mentioned above, the thermal cutout is heated by the excessive flow of current through the heat coil and opens at point 2. The flow of current is stopped no matter how cold the exterior of the motor may be. If the motor does not properly come up to speed,

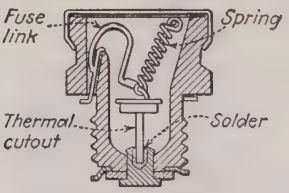


FIG. 80.—Construction of time-lag fuse of screw-base type. (*Bussmann Manufacturing Co.*)

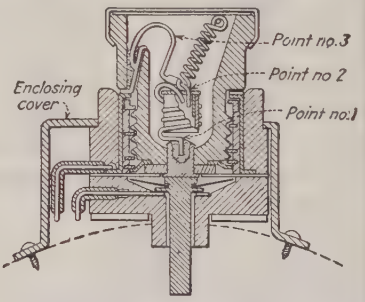


FIG. 81.—Time-lag fuse for protection of small motors. (*Bussmann Manufacturing Co.*)

owing to low voltage, tight belt, dry bearings, or any other cause, the time-lag fuse will open at point 1 or 2. If the motor should be stalled, the excessive flow of current would cause the time-lag fuse to open at point 2. If a short or ground should occur, the excessive current would cause the fuse to open in the fuse link, point 3.

57. Receptacles for mounting time-lag fuses on small motors are made in four types as shown in Fig. 82.

The Type B receptacle is for external mounting and has the heat pin recessed $\frac{1}{8}$ in. within the receptacle. It should be used on split-phase and capacitor motors which have no air duct between the frame and the field laminations, and on totally enclosed motors. In such motors the heat of the windings is readily transmitted through the motor iron to the bottom of the time-lag fuse.

The external Type C receptacle should be used on split-phase and capacitor motors which have an air duct between the frame and the field laminations, and on all repulsion induction motors. In such motors it is

important to get as much of the winding heat to the time-lag fuse as possible. Therefore it has a protruding heat pin, which can be of any length and positioned near the windings so that their heat can be readily conducted to the fuse.

The Type D and Type E receptacles are for internal mounting. The Type D receptacle has the heat pin recessed ⅛ in., and Type E is furnished with a protruding heat pin of any desired length.

These two types of receptacles can be used on any motor. Which type to use will depend on the physical construction of the motor. For example, on some motors there would not be available space to use a receptacle with a protruding pin, such as Type E. On the other hand, when the internal receptacle is to be mounted on a large repulsion induction motor,

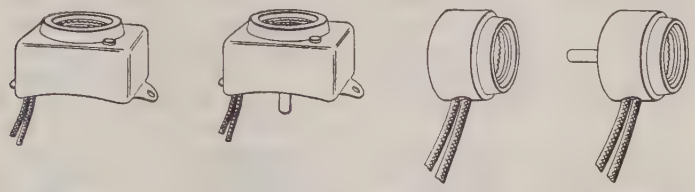


FIG. 82.—Receptacles for mounting fustats on motors. (*Bussmann Manufacturing Co.*)

it might be desirable to use a receptacle with a long heat pin to get as near the commutator as possible.

58. Methods of mounting the different types of receptacles on small motors are described below and illustrated in Fig. 83. Each receptacle is furnished with two No. 6 drivescrews for mounting. Holes for these should be made with a No. 31 drill (0.120 in.). Just drill a hole at least ¼ in. deep, insert the screws, and drive them in with a hammer. Each receptacle is furnished with two 9-in. leads. Connect the receptacle on one side of the line in series with the motor so that unscrewing the fuse shuts off the motor.

TYPE B RECEPTACLE MOUNTING.—The Type B receptacle should be mounted on the laminations or on the frame of the motor but not on the end plates. A hole for the leads must be provided. It must be at least 5/16 in. and may be as large as ¾ in.—the larger the better.

TYPE C RECEPTACLE. NO. 10 MOUNTING.—The Type C receptacle can be mounted on the frame of the motor but not on the end plates. It must be mounted on the air-exhaust end of the motor. Full protection will not be obtained if mounted on the air-intake end of the motor.

The hole for the protruding pin must be ½ in. minimum and may be as large as 1 in. This hole should open directly into the air space above the windings.

The pin is electrically "alive" and must be kept at least $\frac{1}{8}$ in. from the windings or the iron. If the pin is too long for the particular motor to which it is being attached, leave the fuse screwed tightly in the receptacle and cut the pin off to the desired length.

If the hole for the pin is less than 1 in. in diameter, it is necessary to provide another hole for the leads, at least $\frac{5}{16}$ in. in diameter.

TYPE C RECEPTACLE. NO. 11 MOUNTING.—On some types of motors, where the thickness of stator iron and the outside iron are quite considerable, it has been found that the opening time of the time-lag fuse may be

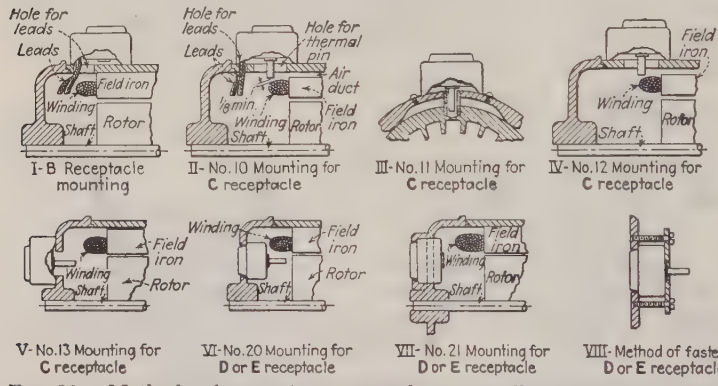


FIG. 83.—Methods of mounting receptacles on small motors for protection with time-lag fuses.

delayed enough to permit the motor temperature to rise over the safety point. In such cases, a paper or fiber tube with $\frac{1}{4}$ in. inside diameter, dropped into the pin hole, causes the fuse to operate at a lower motor temperature.

On highly ventilated motors, with fuse mounted over the field laminations, it is absolutely necessary to have a hole to a depth about $\frac{1}{16}$ in. from the wire slot and to have the pin projecting into this hole but not closer to the bottom than $\frac{1}{8}$ in. It is also necessary to insulate the pin with a fiber or paper tube ($\frac{1}{4}$ in. inside diameter) to prevent the air drawn through the motor from cooling the pin to such an extent as to prevent opening of the fuse when prohibitive temperature has been reached.

NOTE. This mounting should never be used on repulsion induction motors of $\frac{1}{3}$ hp. or larger.

TYPE C RECEPTACLE. NO. 12 MOUNTING.—This mounting can be used instead of No. 10 or No. 11 when it is not desirable to drill the field laminations. This type mounting can also be used on all repulsion induction motors. The receptacle must be put on the air-exhaust end of

the motor. Good protection will not be obtained if the mounting is made on the air-intake end of a motor.

The hole for the heat pin should be made as large as possible. Obviously, 7/16 in. is as small as it can be to meet the electrical requirements, but to ensure good conduction of heat to bottom of the receptacle this hole should be as large as possible.

Type C Receptacle. No. 13 Mounting.—An alternate for No. 12 mounting, this method is very often desirable on vertical motors, as well as other motors where only the end bell is available for mounting.

This type of mounting must be put on the air-exhaust end of the motor, and the hole for the heat pin should be as large as possible.

Type D or E Receptacle. No. 20 Mounting.—The simplest form of mounting the internal receptacle is shown in the drawing. All that is required is a 1¼-in. hole, which can be either drilled or cast in the end bell.

This type of mounting must be on the air-exhaust end of the motor.

Type D or E Receptacle. No. 21 Mounting.—Where sufficient space is not available to use the No. 20 mounting, a slight change in the end-bell casting can be made, as shown.

This type of mounting must also be on the air-exhaust end of the motor.

Fastening Type D or E Receptacle.—The easiest method of fastening the Type D or E receptacle is illustrated. The receptacle is inserted in the hole and held in place by a flat metal strap secured to the end bell by two screws.

59. The internal construction of a cartridge time-lag fuse of the nonrenewable type is shown in Fig. 84. It consists of a copper heat coil *A* at

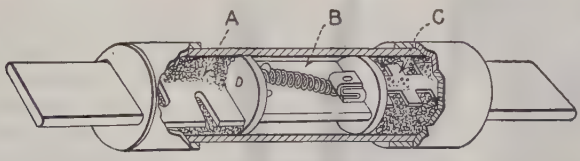


Fig. 84.—Nonrenewable time-lag cartridge fuse. Fusetron of the Bussmann Manufacturing Co.

one end, a heavy copper center strap *B*, and a copper fuse link *C* at the other end. Parts *A* and *B* are called the thermal-cutout portion of the fuse. They handle light overloads up to 500 per cent of the fuse rating. The fuse link handles heavy overloads in excess of 500 per cent of the fuse rating. The center copper strap *B* is held in position by means of a soldered connection to a spring. Light overloads will not blow the fuse link but will open the circuit through the action of the thermal-cutout parts. The heat coil *A* is heated by these light overloads causing heat to flow into the heavy copper strap *B*. When *B* is heated up to the melting point of the solder, the spring is released and the thermal-cutout portion opens. The heat coil and center strap are quite heavy so that it takes

considerable time to raise the temperature of the strap sufficiently to melt the solder. This feature together with the time required to melt the solder gives the fuse its time-lag characteristics. On heavy overloads the fuse link blows immediately before the thermal-cutout portion has time to function.

60. Super-time-lag fuses of the renewable type obtain their time-lag characteristic through a special link construction (Fig. 85). In the super-

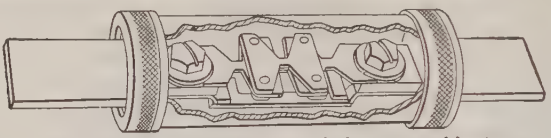


FIG. 85.—Cutaway view of time-lag fuse of the renewable type. Super-lag fuse of the Bussmann Manufacturing Co.

lag fuse, heavy lag plates are attached to the center of the link. The principal blowing parts of the fuse are near the terminals. The heavy lag plates keep the center of the link relatively cool. An extra reduced section is provided in the center of these lag plates so that they do not increase the current-carrying capacity of the link too much. As a result the lag plates serve only to help the terminals conduct away and temporarily store some of the heat generated in the weak spots so that it takes a longer time to get the weak spots heated sufficiently to blow. Thus a time lag is obtained far in excess of other types of fuses.

I. Cutaway view of assembly

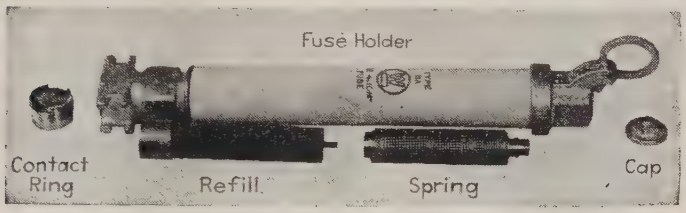
II. Fuse link of cutout

FIG. 85A.—D. & W. oil fuse cutout. (*General Electric Co.*)

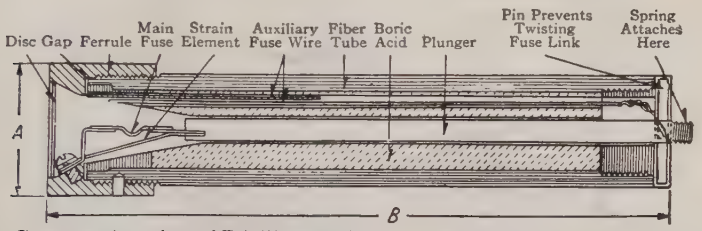
On light overloads the center weak spot of the super-lag link will sometimes burn out. This is because the rise in temperature of the entire strip is so gradual that the heavy metal terminals of the fuse can conduct the heat away from the end weak spots fast enough to keep them relatively cool. Whether or not the two end weak spots or the center weak spot of the buss super-lag fuse blows first, it makes no difference in regard to the superior time lag that is obtained through the use of the lag plates.

When a short circuit occurs, the two end weak spots melt instantaneously and because of the well-known fact that two arcs in series cannot maintain themselves as long as a single arc on the same voltage, much less metal is vaporized

The thick lag plates also serve to reduce the amount of metal vaporized. First, their cooling effect at ordinary overloads makes it possible to reduce



I. BA "De-ion" fuse. Disassembled view



II. Cross-section view of BA "De-ion" power-fuse refill showing construction details

FIG. 85*B*.—High-voltage power fuse of the boric acid type. (*Westinghouse Electric & Manufacturing Co.*)

the amount of metal in the weak spots. Second, the thick lag plates in the center of the link serve to keep cooler the entire mass of metal in the center, and therefore the arc that follows the short circuit cannot as readily melt this center section. As a consequence of this, less metal is vaporized on short-circuit blows than on any other type of fuse. This means that less pressure is created in the fuse, and therefore the danger of a fuse rupturing or exploding or belching fire on short circuits is considerably less than on any other fuse.

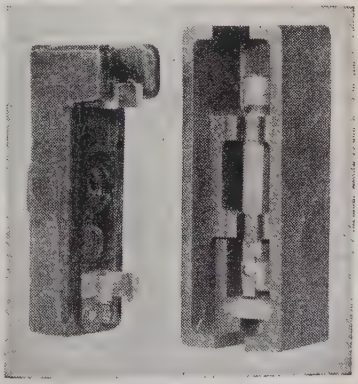


FIG. 85*C*.—Fuse for high-voltage potential transformer. (*Westinghouse Electric & Manufacturing Co.*)

60A. High-voltage Fuses.—Fuses for circuits having a voltage greater than 600 are specially constructed so that they will be safe for the interruption of current under these voltages. Two types for protection of power circuits are shown in Figs. 85*A* and 85*B*. The fuse of Fig. 85*A* is of the oil-fuse cutout type. The fuse link shown at II has a section of

fusible alloy at the bottom. The entire link except the top laminated-metal terminals is enclosed in flat tubing of insulating material. The link is mounted in a casing and immersed in oil. The fuse of Fig. 85*B* consists of a tube lined with boric acid, which provides a source of deionization for extinguishing the arc. A high-voltage fuse for protecting a potential transformer is shown in Fig. 85*C*.

61. A thermal cutout (Figs. 86 and 87) is an inverse-time-limit overload protective device. Its general construction and appearance are very similar to a plug fuse, except that it is much larger.

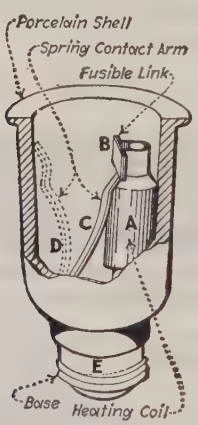


FIG. 86.—General Electric thermal cutout.

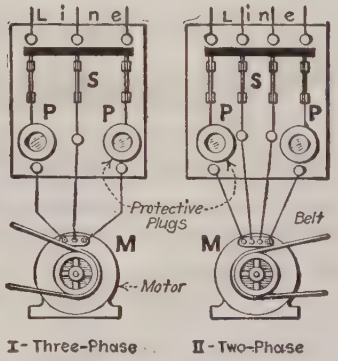
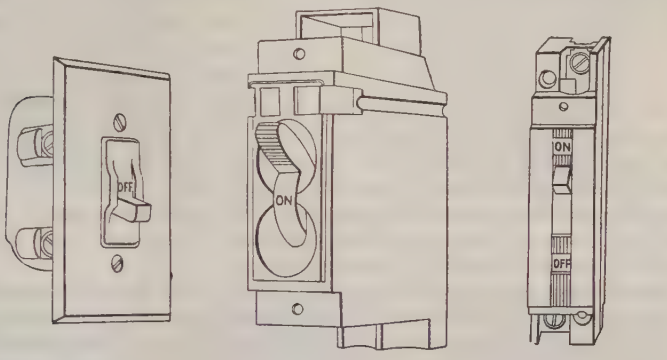


FIG. 87.—Application of thermal cutouts.

The base *E* has a left-hand thread making it impossible to substitute this for a regular fuse plug. It will fit a cutout (see Fig. 77) which has a screw shell with a left-hand thread. The plug is designed especially for the protection of motors against excessive overloads such as (1) motors called upon to drive too heavy overloads, (2) motors stalled when attempt is made to start them, and (3) polyphase motors running single-phase. The plugs are manufactured in various capacities for the protection of motors up to 3 hp., 110 volts; 5 hp., 220 volts; or 7½ hp., 440 and 550 volts.

EXPLANATION.—The motor current flows through the heating coil *A*. The temperature of this coil increases quickly with heavy overloads but slowly with light overloads. The heat from this coil, if it is raised to a sufficiently high temperature by the continued flowing of the overload current, melts the fusible link *B*. This permits the spring contact *C* to fly to the position *D*. Thereby the motor *M* is disconnected from the circuit before it can be damaged by overheating. The General Electric Co. manufactures a specially designed enclosed switch *S* (Fig. 87), in which the plugs *P* are inserted, which is adapted for the starting of small motors.

62. A circuit breaker is a switching device which is designed to open a current-carrying circuit under abnormal current conditions without injury to itself. It is adjusted to interrupt the current upon the occur-



I-Thermal breaker for mounting in outlet box or conduit fitting (General Electric Co.)

II-Magnetic breaker for mounting in outlet box or conduit fitting (Heinemann Elec. Co.)

III-Thermal breaker for panelboard mounting (Westinghouse Elec. & Mfg. Co.)

FIG. 88.—Small circuit breakers for branch circuits.

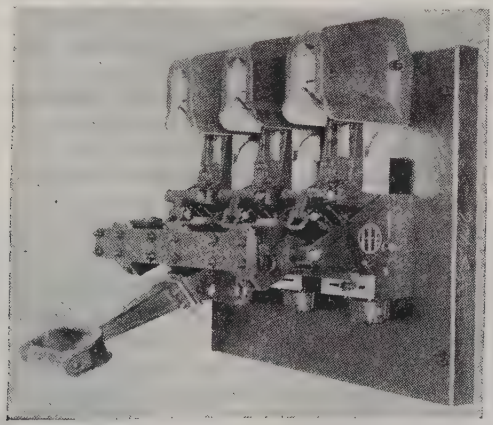


FIG. 89.—Magnetic air circuit breaker for switchboard mounting. (*I-T-E Circuit Breaker Co.*)

rence of an overload of definite amount. It must be capable of interrupting short-circuit currents. The distinction between circuit breakers and switches is in their current-interrupting abilities. A switch is not designed for the interruption of short-circuit currents, while a circuit breaker is.

The actuation of a circuit breaker upon the occurrence of an overload may be performed by means of thermal releases or relays, magnetic releases or relays, combination thermal and magnetic releases, or induction relays. The thermal devices will have inverse-time characteristics. The magnetic and induction devices may be designed for instantaneous-, inverse-, or definite-time action. Release devices are generally employed for manually operated breakers, and relays for electrically operated ones.

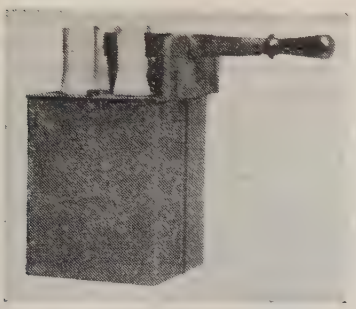
The terms **primary** and **secondary** or **auxiliary circuit breakers** are sometimes employed. So-called secondary or auxiliary circuit breakers are in reality not circuit breakers at all, since they are not capable of satisfactorily interrupting short-circuit currents. Actually they are manual motor-starting switches provided with protection against overload by means of thermal overload releases. The only real circuit breakers are those classed as primary breakers.

Circuit breakers are available to meet the requirements of all classes of service from a small breaker for 15-amp. branch circuits (Fig. 88) to the very large units for controlling large amounts of power. Those used for the protection of branch circuits must be so designed that it is difficult to alter the setting of the current trip point or to change the time required for the operation of the breaker. They may be of the air-break type (Figs. 88, 89, and 91) or of the oil-immersed type (Fig. 90). The air circuit breakers may be of open construction for switchboard mounting (Fig. 89) or of the safety enclosed type for either panel-board mounting (Figs. 88, III; 89; and 91, IV) or individual mounting (Figs. 88, I and II; and 91, I, II, III, and V).

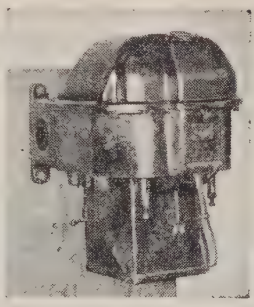
63. Magnetic switches provided with overload protection by means of thermal or magnetic relays are commonly used for the overload protection of motors. These switches are discussed in Div. 7.

63A. Manual switches provided with overload protection by means of thermal releases are commonly used for the combined purpose of motor starters and motor overload protection. They are discussed in Div. 7.

64. Thermal relays are made in several different forms, depending upon the ideas of the manufacturer. They provide inverse-time overload protection. The greater the overload, the shorter the length of time required for the relay to function. One type of thermal overload relay, manufactured by the Trumbull Electric Manufacturing Co., is shown in Fig. 92. The outside appearance is somewhat similar to ferrule-contact cartridge fuses. It is supported by standard 60-amp. fuse clips. The length of the relay is greater than that of standard fuses so that the clips must be spaced farther apart. This prohibits the substituting of the relay in place of fuses. The thermostatic element C consists of a strip of brass electrically welded to a strip of steel. When heated, the brass expands more than the steel and therefore causes the element to curve. The main-line current passes from the ferrule contact F, through the heating element A, through copper contact block B, and thence to ferrule

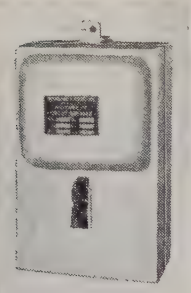


I. Switchboard mounting type



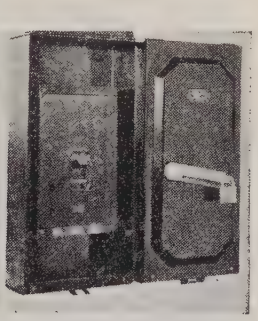
II. Industrial type

FIG. 90.—Oil circuit breakers. (*Westinghouse Electric & Manufacturing Co.*)

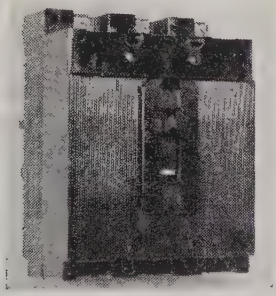


I. Small-capacity magnetic breaker (*Heinemann Electric Co.*)

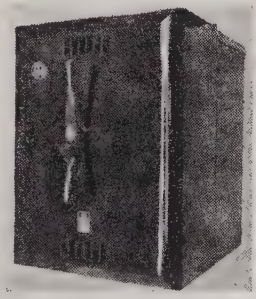
II. Small-capacity thermal breaker (*I-T-E Circuit Breaker Co.*)



III. Medium-capacity thermal breaker (*I-T-E Circuit Breaker Co.*)



IV. Medium-capacity thermal breaker for panel mounting. (*I-T-E Circuit Breaker Co.*)



V. Large- or medium-capacity magnetic breaker (*I-T-E Circuit Breaker Co.*)

FIG. 91.—Safety enclosed air circuit breakers.

contact G. In case of overload, excess heat in element A is transmitted to the thermostatic element C through block B. This heat causes the thermal element C to curve and break the contact at D. The contact D is placed in series with an undervoltage release coil or the operating coil of a magnetic switch. The thermal relay does not itself interrupt the main current. It simply opens an auxiliary circuit which actuates the switch mechanism. The asbestos strip E shields the thermal element C from the direct heat of element A. The heating of element C by the conduction of heat from element A to copper block B gives the relay its proper time lag for its inverse-time characteristic. With slight overload it takes considerable time for the heat to be transmitted to element C, while with heavy

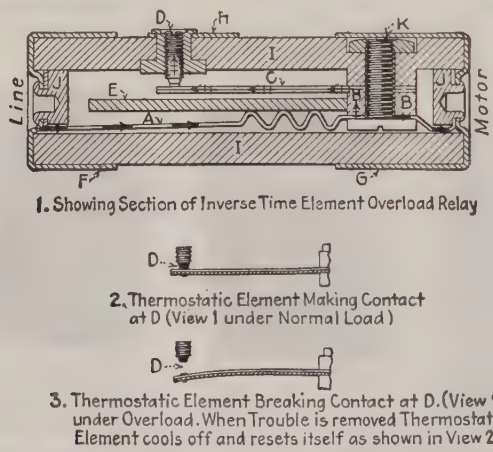


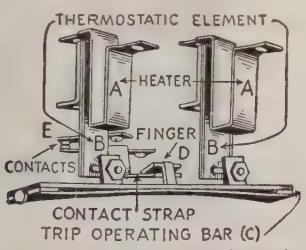
FIG. 92.—Thermal overload relay. (*Trumbull Electric Manufacturing Co.*)

overloads it takes only a short time for element C to become heated and operate. The relay illustrated is of the self-resetting type. As the thermal element cools, it straightens out and returns to the normal position. There is nothing to be replaced after the occurrence of an overload. These relays are made also in the hand-reset type. They are the same as the self-resetting type, except that, after tripping, the thermostatic element is held in the curved position until it is released by hand.

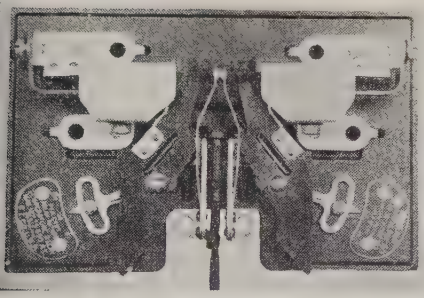
Other thermal relays are shown in Fig. 93. The operation of the automatic-reset overload trip shown in Fig. 93, I, is as follows: On overload the heater A becomes excessively hot. The heat is communicated to adjacent thermostatic element B, pulling forward the trip operating bar C far enough for finger D to press down on contact strap and open contacts at E. After overload the heaters automatically reset after a reasonable length of time.

Thermal relays are extensively used in connection with magnetic switches for the overload protection of motors. They are not generally employed with circuit breakers.

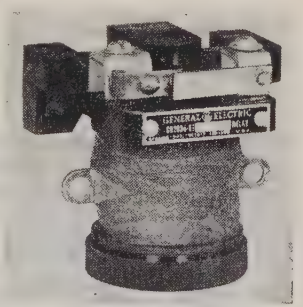
64A. Thermal overload release devices operate on the same general principle as thermal relays. The essential difference is that the thermal element of the release device in expanding acts directly upon the holding



I. Trumbull Electric Manufacturing Co.



II. General Electric Co.



III. Thermal-inductive. (*General Electric Co.*)

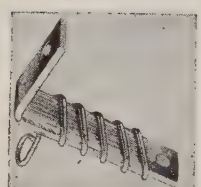
FIG. 93.—Overload thermal relays.

catch of the switch or circuit breaker, while the relay opens an auxiliary circuit which trips the switch. The relays are used on magnetic switches, and the release devices on manually operated switches and circuit breakers. Overload release devices are shown in Fig. 94.

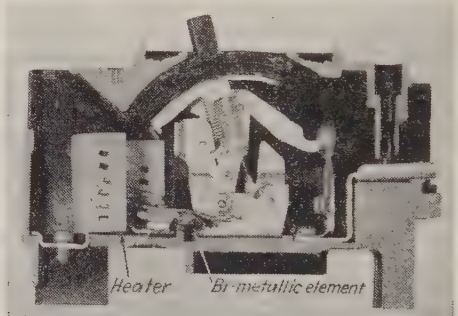
65. Magnetic relays and magnetic overload release devices consist of a solenoid acting upon an iron plunger or armature (Fig. 95). The coil of the solenoid is connected in series with the circuit to be protected or frequently in a-c circuits to the secondary of a current transformer which has its primary connected in series with the main circuit. The current at which the relay will function can be regulated by adjusting the height of the plunger or the position of the movable armature. Instantaneous-type relays and overload release devices function instantaneously upon

the occurrence of an overload of any value of current above that for which the device is set.

By the attachment of an air bellows or an oil dashpot to the plunger



I. Thermal heater element used in motor-control equipment. (*Trumbull Electric Manufacturing Co.*)



II. Thermal overload release mechanism for thermal breaker. (*I-T-E Circuit Breaker Co.*)

FIG. 94.—Thermal overload releases.

the device can be given inverse- or definite-time characteristics. With the inverse-time type, the time that an overload must exist, before the device functions, is inversely proportional to the severity of the overload.

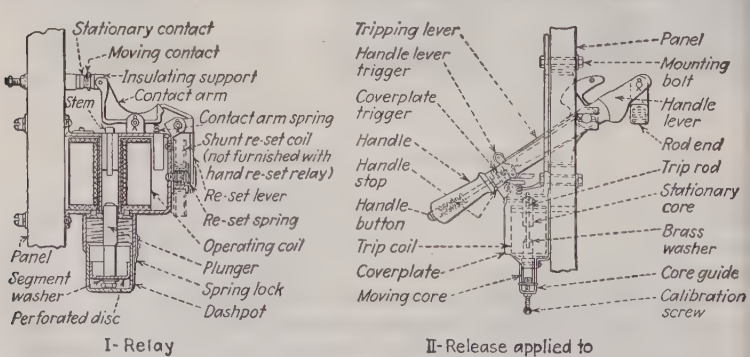


FIG. 95.—Magnetic overload relay and release. (*Westinghouse Electric & Manufacturing Co.*)

A slight overload must continue for a considerable time, before the device will function, while a heavy overload will cause the device to function almost instantaneously. With the definite-time type, the device does not

function until the overload has persisted for a certain definite length of time, depending upon the setting of the device. The elapsed time between the occurrence of the overload and the functioning of the device does not depend upon the severity of the overload. The essential difference between a magnetic relay and a magnetic overload release device is the same as for thermal relays and thermal overload release devices. The overload release device acts directly upon the catch of the switch mechanism, while a relay acts upon an auxiliary circuit which in turn trips the switch mechanism.

Magnetic relays are used in conjunction with circuit breakers, and magnetic switches for overload protection. Magnetic overload release devices are employed in conjunction with circuit breakers only.

66. Induction-type overload relays are seldom used for ordinary interior-wiring work. They are widely used by central-station companies for protection of circuits and apparatus. A detailed discussion of these relays is outside the scope of this book. Induction relays operate upon the general principle of induction motors and, therefore, are applicable only to a-c systems. They may be obtained with instantaneous-, inverse-, or definite-time characteristics.

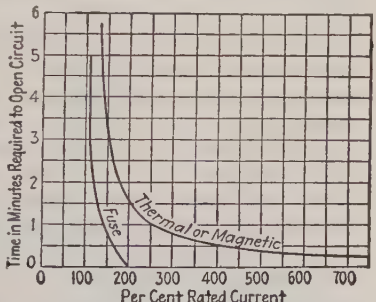


FIG. 95*A*.—Time-current characteristics of overload protective devices.

67. Comparison of the Time Characteristics of Overload Protective Devices.—Typical time-current characteristics of the different overload protective devices are illustrated in Fig. 95*A*. The curve shown for thermal and magnetic devices is typical. All such devices will have a characteristic of the form shown, although different devices, depending upon design, will vary from that shown in time of opening of circuit for the various overloads. Time-lag fuses have characteristics similar to that shown for the thermal and magnetic devices. The curve labeled "fuse" is for the regular type of fuse, not for time-lag ones. It will be noticed that fuses of the regular type have a considerable time-delay characteristic. They will not blow immediately on an overload unless the overload is approximately 200 per cent or greater than the rating of the fuse. Fuses will carry indefinitely a current of 100 per cent of their rating. The inverse-time overload protective devices of the thermal, magnetic, and time-lag fuse types have a greater time-delay characteristic than regular fuses and will, therefore, allow much greater overloads for a short period without interrupting the circuit. These inverse-time characteristics make these overload protective devices ideal for the overload protection of motors. They will allow the heavy starting current to pass but will

protect the motor against sustained overloads that would be harmful to it. They will also permit the motor to operate with intermittent peak overloads of short duration. If fuses are used for the overload protection of induction motors, the fuses must be shorted during the starting period, for a fuse of proper rating to protect the motor would not allow the starting current to pass. Although fuses will permit a motor to operate with moderate intermittent peak overloads, they are not nearly so flexible in this respect as the thermal and magnetic protective devices. Devices with the inverse-time characteristic are also advantageous for protection of circuits, since they will prevent interruption of the circuit due to short overloads, which, although of high magnitude, would be harmless to the circuit.

68. Protection other than overload protection can be provided by means of release devices or relays employed in connection with circuit breakers or magnetic switches.

Undervoltage protection may be provided by means of relays or releases actuating hand-operated circuit breakers, or magnetic switches. On magnetic switches, undervoltage protection is generally provided through the operating coil of the switch. When the voltage drops below a certain value, the current of the operating coil is so reduced that it will no longer hold the switch in the closed position.

Underload, overvoltage, or reverse-current, power, or phase-rotation protection can be provided by means of relays employed in connection with circuit breakers or magnetic switches.

69. Lightning Protection.—High voltages may be electrostatically induced in outdoor electric lines during lightning storms. These voltages produce traveling surges of high voltage which travel along the lines and into electrical equipment, whether it be located outdoors or inside buildings. The high induced voltages would puncture the insulation of equipment and be dangerous to life. Lightning arresters are used to limit these voltages to a safe value and provide a path to ground for the dissipation of the energy of the surge. In order to provide this protection satisfactorily, lightning arresters must fulfill the following functions:

1. They must not allow the passage of current to ground so long as the voltage is normal.

2. When the voltage rises to a definite amount above normal they must provide a path to ground for dissipation of the surge energy without further rise in voltage of the circuit.

3. As soon as the voltage has been reduced below the setting of the arrester, it must stop the flow of current to ground and reseal itself so as to insulate the conductor from ground.

4. They must not be injured by the discharge and must be capable of automatically repeating their action as frequently as is required.

Lightning arresters should be provided on all overhead systems. For the small consumer who purchases his power from a public utility, this

protection is supplied by the utility on their distribution circuits. For a large consumer it may be advantageous to install lightning arresters located between the public-utility lines and the consumer's substation. All communication circuits entering a building must be provided with a protector which will give protection against abnormal voltage to ground caused not only by lightning but by accidental contact between communication circuits and power circuits. This protection is usually provided by the communication company which is supplying the service. All signal circuits which are run outdoors for any part of their length or which are installed so that there is any possibility of accidental contact between the signal circuit and power conductors must be provided with a protector.

Radio equipment is required by the National Electrical Code to be protected against lightning as follows:

Receiving Stations.—Each conductor of a leadin from an outdoor antenna shall be provided with a lightning arrester approved for the purpose, except that if the leadin conductors from antenna to entrance to building are enclosed in a continuous metallic shield, the lightning arrester may be installed to protect the shield or may be omitted if the shield is permanently and effectively grounded. Lightning arresters shall be located outside the building, or inside the building between the point of entrance of the leadin and the radio set or transformers, and as near as practicable to the entrance of the conductors into the building. The lightning arrester shall not be located near combustible material or in a hazardous location.

Outdoor grounding conductors shall be not smaller than No. 14 copper or No. 17 copper-clad steel or bronze. Wholly indoor grounding conductors shall be not smaller than No. 18.

Transmitting Stations.—Except where protected by a continuous metallic shield which is permanently and effectively grounded, or where the antenna is permanently and effectively grounded, each conductor of a leadin for outdoor antenna shall be provided with a lighting arrester or a grounding switch or other suitable means which will drain static charges from the antenna system. The grounding conductor shall be the same size as the lead-in conductor but not smaller than No. 14.

70. Lightning arresters are made in many different forms. A discussion of the construction, application, and installation of the various types is outside the scope of this book. Typical types for power work are illustrated in Fig. 96, and types for signal and communication work in Fig. 97.

Lightning arresters may be installed indoors or outdoors. When located indoors they must be located well away from other equipment, passageways, and combustible material or parts of the building, and if they contain oil they must be enclosed in vaults of construction similar to that required for oil-filled transformers (see Div. 5). If arresters which contain oil are located outdoors, provision must be made to drain away

any accumulation of oil. This may be done by properly constructed ditches and drains, or the oil may be absorbed and danger of spreading

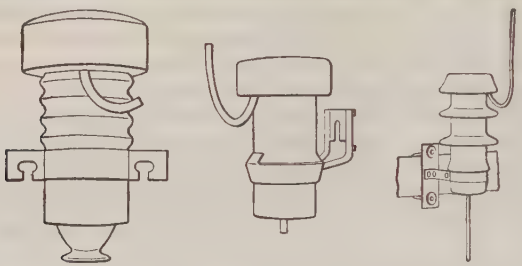
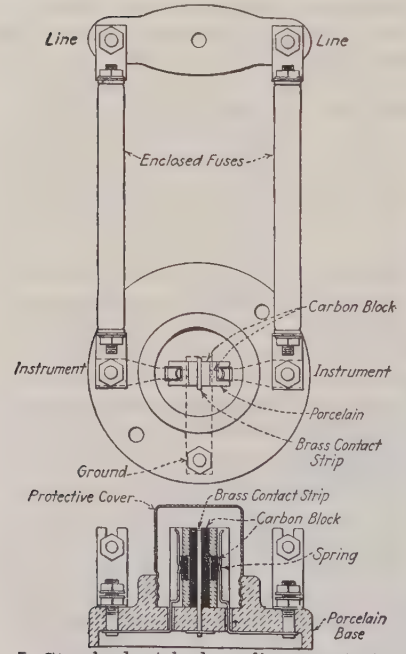
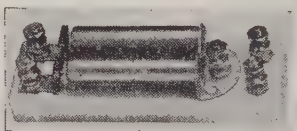


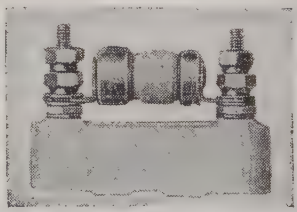
FIG. 96.—Lightning arresters of the power type.



I. Standard telephone-line protector



II. Arrester for signal circuits. (*General Electric Co.*)



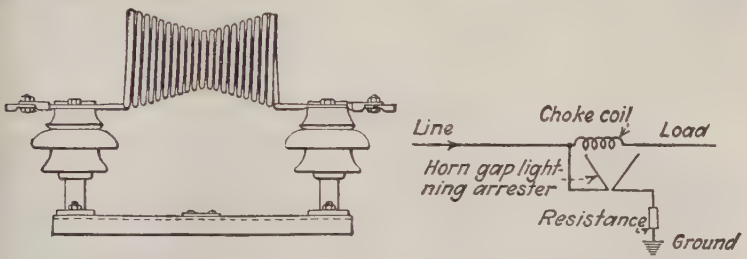
III. Arrester for signal circuits. (*Electric Service Supplies Co.*)

FIG. 97.—Lightning arresters of the low-voltage type.

removed by paving the yard with cinders or other absorbent material to a depth of several inches.

An arrester must not be located in a hazardous location (see Div. 9)

When lightning arresters are used, an arrester should be installed for each ungrounded circuit wire.



I. Choke coil and support for outdoor service

II. Circuit diagram showing location of choke coil

FIG. 98.—Choke coil for use with lightning arrester. ("*Electric System Handbook.*")

Proper grounding of lightning arresters is of utmost importance. Refer to Div. 9 for discussion of grounding rules and practice.

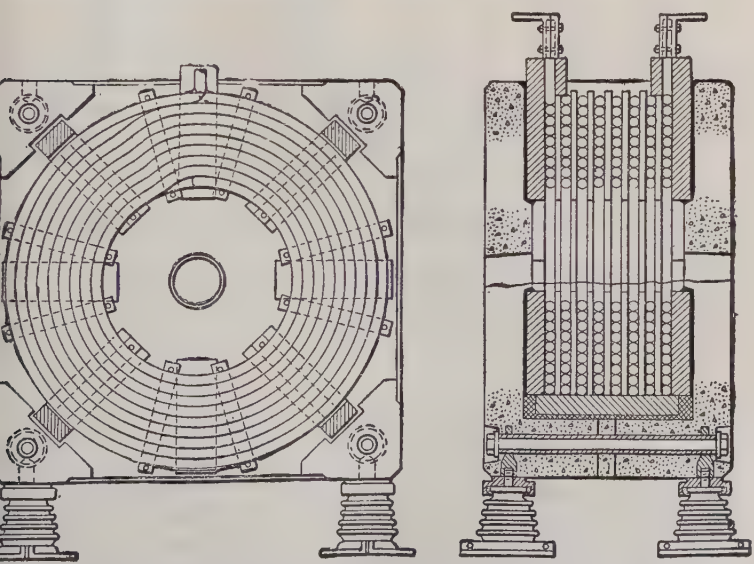


FIG. 99.—Current-limiting reactor, series wound with single insulated cable—horizontal axis. ("*Electric System Handbook.*")

71. Surge protective equipment is used in connection with lightning arresters and in large power systems for limiting the value of short-circuit current. They consist of coils of wire connected in series with the circuit

for the purpose of introducing inductance. Those used with lightning arresters are called choke coils (Fig. 98). The inductance of the coil tends to shunt the high-frequency lightning surge away from the apparatus and through the arrester to ground. Those used for limiting short-circuit currents are called reactors. A typical construction of a reactor is shown in Fig. 99.

SWITCHBOARDS

72. A switchboard as defined in the National Electrical Code is a large single panel, frame, or assembly of panels, on which are mounted, on the face or back or both, switches, overcurrent and other protective devices, busses, and, usually, instruments. Switchboards are generally accessible

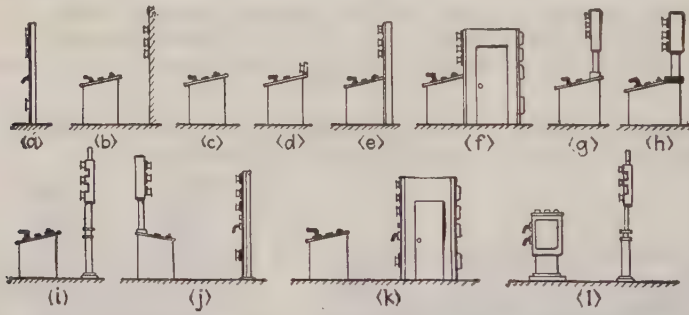


FIG. 100.—Commonly employed combinations of panel, desk, pedestal, and post. ("*Electric System Handbook.*")

from the rear as well as from the front and are not intended to be installed in cabinets.

73. The types of switchboards that are in common use are as follows:

1. Live-front vertical panels.
2. Dead-front boards.
   - *a.* Vertical panels.
   - *b.* Bench or desk.
   - *c.* Pedestal and post.
   - *d.* Combination.
3. Safety enclosed boards (metal-clad).
   - *a.* Unit or sectional.
   - *b.* Truck or draw-out type.

Live-front switchboards (Fig. 101) have the current-carrying parts of switching equipment mounted on the exposed face or front of the panels. They are not as a rule employed in new boards where the voltage exceeds 600 volts

Dead-front switchboards (Fig. 102) are the more modern type and are employed for systems of all voltages. With this type no live parts are mounted on the front of the board.

Typical switchboard types are shown in Fig. 100.

Unit or sectional switchboards (Figs. 103 and 104) are commonly used for the control of circuits at distribution centers in industrial plants. They consist of boards built up of unit sections of safety enclosed switches or circuit breakers. Each panel is an assembly of formed steel panels suitably mounted in an angle-iron framework.

Truck- or draw-out-type switchboards (Fig. 105) consist of a sheet-steel enclosure mounted on an angle-iron framework. All apparatus which requires attention or inspection is mounted on a truck or draw-out structure. The equipment for each circuit is mounted on either a separate truck, which can be easily rolled out from the rest of the structure, or a metal structure supported on guides so that it can easily be slid in and out from the enclosure (Fig. 106).

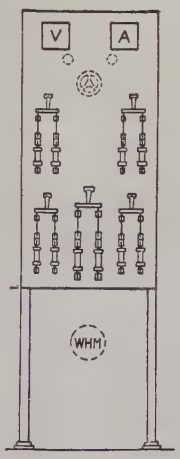


Fig. 101.—Live-front switchboard panel.

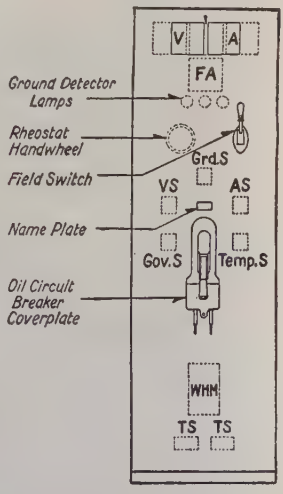


Fig. 102.—Dead-front switchboard panel.

The bench, pedestal-and-post, and combination types are used for the support of control and metering equipment for remote-controlled, electrically operated circuit breakers in central stations.

74. Materials employed for the panels of switchboards are slate, marble, ebony-asbestos, and steel. At one time slate was the material principally used for switchboard panels, but it has been almost entirely replaced by ebony-asbestos for live-front boards and steel for dead-front and safety enclosed ones. Marble is used sometimes on live-front boards for its higher insulation qualities over slate but more often for its better appearance.

The supporting frame for panels may be of angle iron or pipe. Switchboard manufacturers carry a very full line of fittings for almost every desired purpose of mounting equipment for both angle and pipe framework construction.

75. Location of Switchboards.—Switchboards of the safety enclosed type may be placed in any nonhazardous location without any restrictions. Switchboards with any exposed live parts must be located in permanently dry locations and only where they may be under competent supervision and accessible only to qualified persons. The rear of a switchboard may be made accessible only to qualified persons by a metal grillwork enclosure, entrance to which is by means of a locked door.

FIG. 103.—Unit-type, safety enclosed switchboard, Trumbull Electric Manufacturing Co. Swing-Wa type.

Switchboards should be located so as to reduce to a minimum the probability of communicating fire to adjacent easily ignitible material. A clearance of at least 3 ft. must be left between the top of a board and a nonfireproof ceiling unless an adequate fireproof shield is provided between the board and the ceiling. If the equipment or wiring on the back of a board is accessible only from the rear of the board, the National Electrical Code requires that a clear space of at least 18 in. between such equipment or wiring and the wall for a single-panel board not exceeding

42 in. in width be provided, and that a clear space of at least 24 in. be provided for all other boards. When the space behind the board is accessible from only one end, the above clearances must be increased by 6 in. The above clearance of 24 in. may be reduced to 18 in. for short intervals at building-column locations. The space back of a panel must be kept clear of all foreign material and never be allowed to be used as a storage space.

76. Foundations for open switchboards should be carefully installed. The following instructions are given by the General Electric Co.

The switchboard should stand on a level foundation sill made of hardwood or channel iron (see Figs. 107, 108, 109, and 110). The sill must be rigid and heavy enough so that the panels will not be thrown out of line by settling. Standard 6-in. channels are best, although hardwood sills 7 by 2 in. may be used and are recommended where insulated framework is required. The sill should be securely anchored. Drill the channel sill for anchor bolts to suit floor construction.

Figure 111 shows a method of grouting the channels. A small brick pier should be built at each end, and sand or plaster piled along the sides of the channel to prevent the cement from leaking out. The mixture should be about 1 part sand to 1 part cement and should flow freely. By pouring it into the piers until the level rises above the top of the channel, a head will be produced which will force the cement underneath the channel. Another method of grouting recommended by the Westinghouse Electric & Manufacturing Co. is shown in Fig. 112.

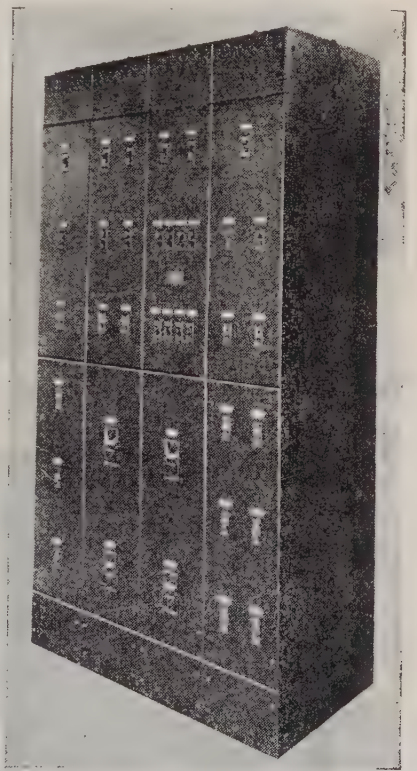


Fig. 104.—Unit-type, safety enclosed circuit-breaker switchboard. (*Trumbull Electric Manufacturing Co.*)

The tapped holes in the sill should be plugged with wood before pouring the cement, or the bolts for the floor flanges should be screwed into the

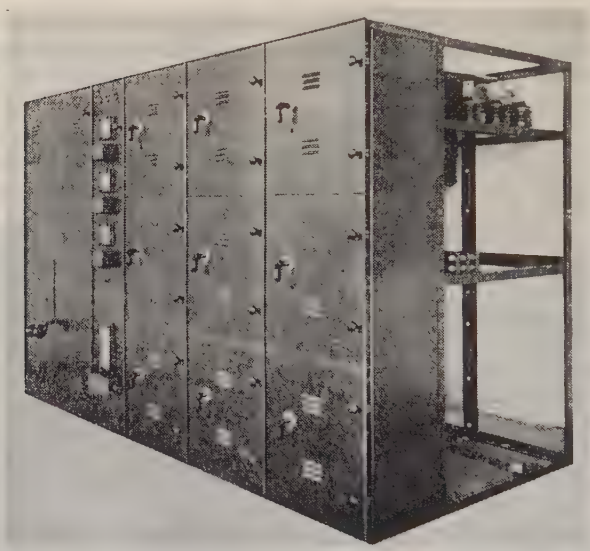


FIG. 105.—Draw-out type of safety enclosed circuit-breaker switchboard.

FIG. 106.—Circuit breaker partly withdrawn from draw-out type of switchboard.

channel temporarily to the maximum depth, in order to prevent the cement from filling them and making it difficult to fasten the flanges to the channel.

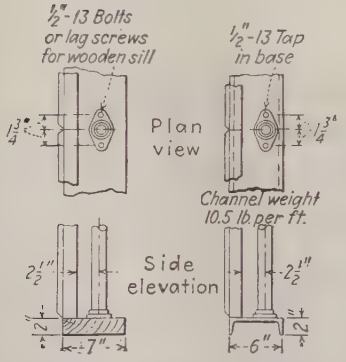


FIG. 107.—Standard sill and switchboard sub-base arrangements.

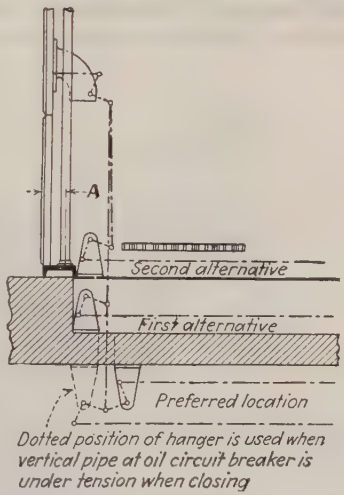


FIG. 108.—Arrangement of channel base, panel sub-base, and panel supports, showing preferred and alternative locations of lower vertical hanger for pipe mechanism, for remote-controlled oil circuit breakers.

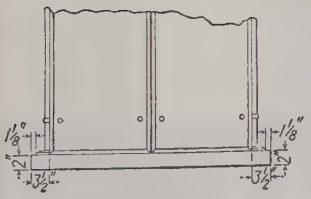


FIG. 109.

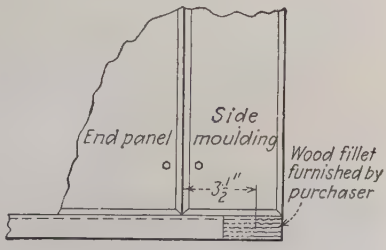


FIG. 110.

FIG. 109.—Arrangement of channel base when end grill is not used.
FIG. 110.—Arrangement of channel base when end grill is used.

The grouting should be allowed to set for 24 hr. before mounting the panels on the sill.

It cannot be too strongly emphasized that the leveling, anchoring, and grouting of the sill are important operations, and the final appearance of the switchboard is dependent largely upon the care and patience exercised.

The method of anchoring panel braces is dependent on construction of the walls. Heavy panel equipment requires solid fastenings. Expansion bolts, through bolts, or an angle iron bolted along the wall may be used.

77. Erection of Switchboard (General Electric Co.).—The panel frame consists of either 1¼-in. upright pipe supports, angle irons, or, in cases

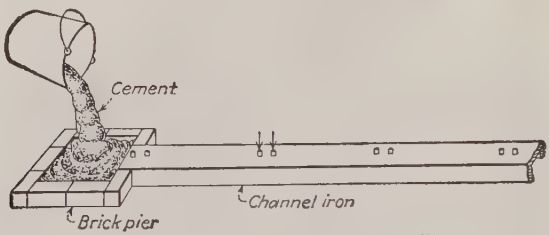


FIG. 111.—Method of grouting sill.

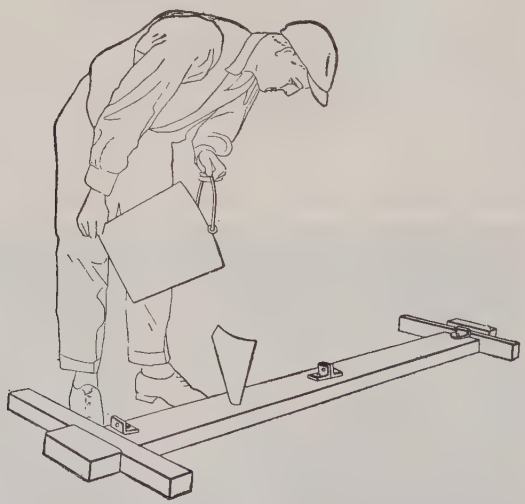


FIG. 112.—Method of grouting sill. After the base has been properly leveled and bolted down, the ends of the channel should be closed as shown and then grouted in by pouring the grout through the large holes provided in the channel for this purpose. Note particularly that the corner angles should not be removed from the channel-iron base until the grouting has set. (*Westinghouse Electric & Manufacturing Co.*)

where the equipment is exceptionally heavy, channel irons. Figures 113 and 114 represent the standard method of bracing switchboard panel supports.

Regardless of frame construction and method of shipping panels, whether assembled or dismantled, the middle panel should be erected

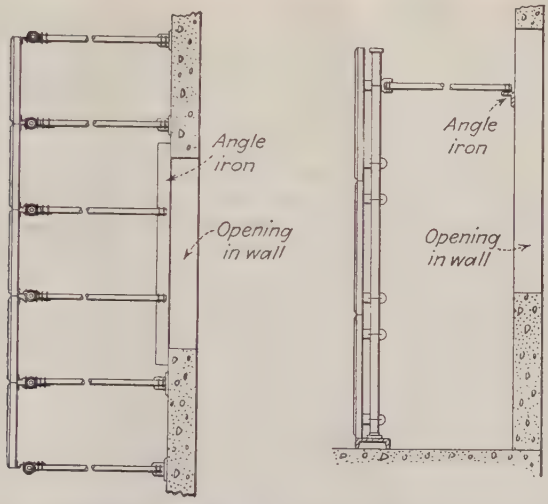


FIG. 113.—A suggested method of bracing a switchboard when it extends across a window or other opening in the wall. An angle iron is bolted across the opening and the rods are fastened to it.

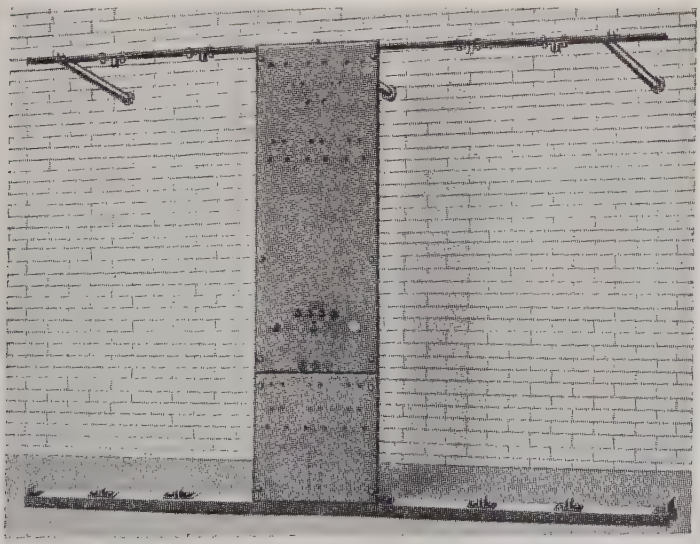


FIG. 114.—Correct method of assembling and aligning switchboard panels. Note that the middle panel has been first placed in position.

first, plumbed, and braced securely. If the supports are shipped separately the framework should be set up and plumbed first, and then the panels bolted to it, first loosely to avoid cracking and then securely. Flexible leatheroid washers are placed between frame and panels to prevent cracking of the panels when the bolts are tightened and to align the front surfaces of the panels. If shipped on supports, each panel will be set up adjacent to the fixed panel and anchored in place. Shimming should be done between the sill and bottom edge of panels to plumb the free edge as illustrated in Fig. 115. Sometimes it may be necessary to file the edges of two adjacent panels by means of a hack-saw blade inserted between them in order to fit them more closely.

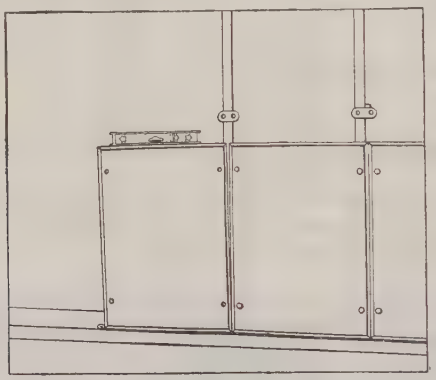


FIG. 115.—Spacers are placed under the lower outside corner of the panel when an opening appears at the top.

The installation work is somewhat simpler when the panels are shipped assembled on their supports, but even then plumbing and shimming may be necessary, as in Fig. 115.

Benchboards are sometimes shipped assembled, but more frequently they are shipped knocked down. In erecting the board the sills are leveled and bolted in place first, and then the frames are set up and anchored to the sills. Next the vertical sections below the bench and then the bench sections are erected, always starting from the middle of the board. Lastly, the instrument sections are set up. The grille or sheet-iron work should be fitted but should not be bolted into place before the wiring has been done.

78. Estimating switchboard dimensions is often necessary for preliminary estimating purposes or in checking to determine if a proposed switchboard will fit in the available space. The data in the following sections will be found useful for this purpose. It is furnished through the courtesy of the Trumbull Electric Manufacturing Co.

$A1$ = single pole
$A2$ = double pole
$A3$ = three pole
$A4$ = four pole

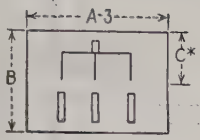


FIG. 116.

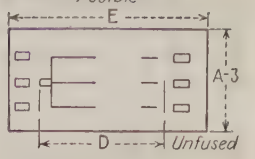


FIG. 117.

All Dimensions in Inches

Amp.	Single throw													Double throw				
	125 volts						250 and 500 volts				250 volts	500 volts	250 and 500 volts	125 volts	250 and 500 volts	125 volts	250 volts	500 volts
	A1	*A2*	*A3*	*A4*	*B*	*C*†	*A1*	*A2*	*A3*	*A4*	*B*	*B*	*C*†	*D*	*D*	*E*	*E*	*E*
30*	2	3¾	5½	7¼	8¼	6¾	2¾	5	7¼	9½	9½	....	7¼	8	9	8½	9½	
60	2¼	4¼	6½	8¼	11	8	3	5¾	8¾	11½	12½	15	8¾	10½	12	12½	14	19
100	3	5¼	7½	9¾	15¼	9¾	3¼	6¼	9¼	12	16¼	18¼	10	13	14¼	17¼	19	23
200							3¾	7¼	10¾	14¾	19	21½	12		16½		23	28
400							4	8¾	12½	16½	23¼	26¼	14¼		21		28¼	34¼
600							4½	8¾	13	17¼	27½	30½	15½		25		33¼	39¼
800 (unfusible)							5	10	15	20	....	....	17¼	Use 250-volt dimension	28½	Use 250-volt dimension		
800 (fusible)							6½	13	19½	26	25	28	....				26½	32½
1,200 (unfusible)							5	10	15	20	....	....	18		28			
1,200 (fusible)							7	14	21	28	26½	29½	....				28¾	34¾
1,600							5½	11	16¼	22	....	....	20		32			
2,000							5½	11	16½	22	....	....	21¾		32½			

NOTE.—Minimum width of panel is summation of width dimensions plus 6 in. Switches fused smaller than the capacity of the switch take the same space as if they were fused to capacity. When switches are rear fused, add 1 in. per pole to *A* dimension. When switches have a larger number of poles than four, use combinations of the *A* dimensions given above, for example, $A5 = A2 + A3$.

* $^{125}/_{250}$-volt dimension. For 500 volts use 60-amp. dimensions.

† *C* dimension is for switches with 90-deg. stops. If stops are not furnished use *D* dimensions.

80. Approximate Space Required for Dead-front Knife Switches

All Dimensions in Inches

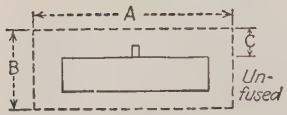


Fig. 118.

Amp.	125–250–500 volts				250 volts	500 volts
	A2	*A3*	*A4*	*C*	*B*	*B*
30 and 60	10	12	15	12	17	17
100	10	12	15	12	19	21
200	11	14	18	13	22	25
400	14	16	21	18	29	32
600	14	17	22	22	36	38
800						
1,200						

Note.—For double-throw switches use twice *B* and *C*.

81. Approximate Space Required on Switchboards for Oil Circuit Breakers

All Dimensions in Inches

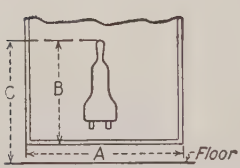


Fig. 119.

Amp.	*A*	*B*	*C*
200– 400	16	22	40
400– 800	24	22	46
800–1,200	24	38	67
1,200–2,000	24	40	68

Space above oil circuit breakers may be used for other equipment if desired. Oil circuit breakers are mounted on individual panels except when two breakers are used together as a motor-starting or double-throw switch, in which case use 24 minus 6 in. for panel width.

82. Approximate Space Required for Thermal-type Circuit Breakers Mounted on Steel Panels

For 600 Volts A.C. or less and 250 Volts D.C.

All Dimensions in Inches

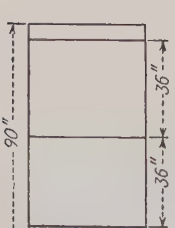


Fig. 120.

Frame capacity of breaker, amp.	2 pole		3 pole	
	Width	Height	Width	Height
50	3½	12	5½	12
100	7	12	10	12
225	7	18	10	18
400	10	24	10	24
600	10	24	10	24

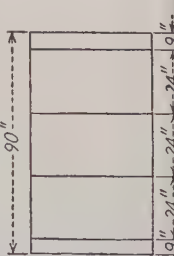


Fig. 121.

The 9-in. sections may be reduced when over-all height of board is less than 90 in. The sections 36 and 24 in. high for mounting breakers are standard and cannot be reduced.

There are only two widths of panels used for mounting thermal-type trip breakers; these are 12 and 16 in.

The 12-in. widths are for mounting three-pole breakers of all sizes up to 225-amp. frame, and for mounting the 400/600-amp. two-pole-frame, either with or without risers. The 12-in. widths are to be used for 400- and 600-amp., three-pole breakers only when risers are used. The 12-in. widths will permit mounting two 50-amp., three-pole breakers or only one each of the higher capacities in a horizontal row.

The 16-in. widths are for mounting two-pole, 50-, 100-, and 225-amp. frame breakers. It will permit four of the 50-amp. frames in one horizontal row and two of the 100- or 225-amp., two-pole frames in one horizontal row. It must be used for the three-pole, 400- and 600-amp. size when supplied without risers to provide sufficient cable clearance. Only one 400/600-amp. breaker can be mounted in a horizontal row.

83. Approximate Space Required for Air Circuit Breakers Other than Thermal Type

All Dimensions in Inches

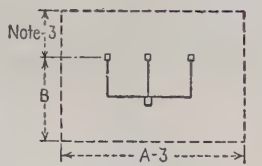


FIG. 122.

Amp.	*A1* = single pole *A2* = double pole *A3* = three pole *A4* = four pole					Add to height *B* for reverse current	Add to width *A* for reverse current	Add to width *A* for under V or shunt T	Panel thickness	Add to height *B* for electrically operated	Dead-front two- and three-pole dimensions (steel panels only)		
	A1	*A2*	*A3*	*A4*	*B*						*A2*	*A3*	*B*
15– 200	6	11	16	21	16	See Note 2		2	1½	8	18	22	23
300– 400	8	13	18	23	18	4	4	3	1½	18	18	22	23
600– 800	9	15	22	28	19	3	4	3	2	17	24	28	30
1,200–1,600	11	18	26	33	20	8	5	3	2	20	24	32	30
2,000–3,000	13	23	35	43	26	8	6	3	3	27	32	44	68
4,000	17	29	41	53	30	6	4	1	3	27	32	44	68

NOTES.—(1) The minimum distance between width dimensions and the edge of the panel is 2 in. (2) Use 300/400-amp. dimensions. (3) Vertical clearance between live-front air circuit breakers shall be not less than 8 in. for 250 volts and 15 in. for 440 volts.

83A. Space Required on Switchboards for Instruments, Etc.—(1) Increase the actual dimensions of instruments or any other equipment not specifically mentioned by 1½ in. in both width and height. (2) The distance to the edge of the panel for this equipment shall be not less than 2 in. (3) The space required by rheostats shall be the space actually required on the back of the panel.

84. Data for Determining Approximate Size and Layout of a Trumbull Swing-Wa Switchboard (Refer to Fig. 123)

This is a very compact board for general-purpose use. The units may be mounted horizontally as well as vertically as shown in the figure.

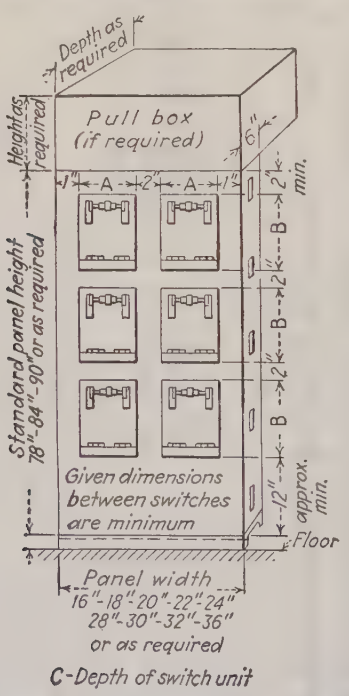


FIG. 123.—Typical layout and dimensional data for Trumbull Swing-Wa switchboards.

Amp.	Volts	A, in.		B, in.	C, in.
		2 pole	3 pole		
30–60–100	250–600	4½	6¾	14¾	4
200	250–600	6¾	10⅛	14¾	4
400	250–600	9	13½	19	4

85. Data for Determining Approximate Size and Layout of a Trumbull F.O.I. Switchboard for Heavy-duty Service (Refer to Fig. 124)

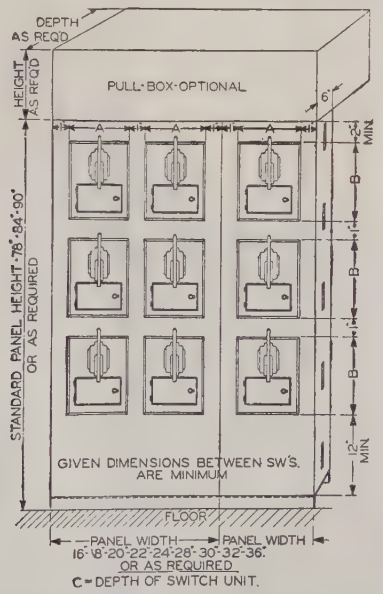


FIG. 124.—Typical layout and dimensional data for Trumbull F.O.I. switch boards.

Amp.	Volts	Poles	*A*	*B*	*C*
30 and 60	250	2	8¾	13⅝	7¾
		3	10⅝	13⅝	7¾
		4	13⅞	13⅝	7¾
	600	2	9¾	17	7¾
		3	11⅝	17	7¾
		4	14⅞	17	7¾
100	250	2	9¾	17	7¾
		3	11⅝	17	7¾
		4	14⅞	17	7¾
	600	2	9¾	19¼	7¾
		3	11⅞	19¼	7¾
		4	14⅞	19¼	7¾
200	250	2	10	18	8¾
		3	11⅞	18	8¾
		4	15⅝	18	8¾
	600	2	10	21½	8¾
		3	12⅞	21½	8¾
		4	16⅝	21½	8¾
400	250	2	13⅝	23¾	11¼
		3	16	23¾	11¼
		4	20¼	23¾	11¼
	600	2	13⅝	27	12¼
		3	16½	27	12¼
		4	21	27	12¼
600	250	2	13⅝	27	12¼
		3	16½	27	12¼
		4	21	27	12¼
	600	2	14	29¼	13
		3	16½	29¼	13
		4	21½	29¼	13
800	250	2	15½	23¾	13
		3	22¾	23¾	13
		4	30	23¾	13
	600	2	17¾	27	13
		3	25	27	13
		4	32¼	27	13
1,200	250	2	17¾	27	13
		3	25	27	13
		4	32¼	27	13
	600	2	18½	30½	13
		3	26	30½	13
		4	33½	30½	13

85A. Data for Determining Approximate Size and Layout for a Trumbull Safety Enclosed Unit Circuit-breaker Switchboard

The data are used in conjunction with the layout information of Fig. 125.

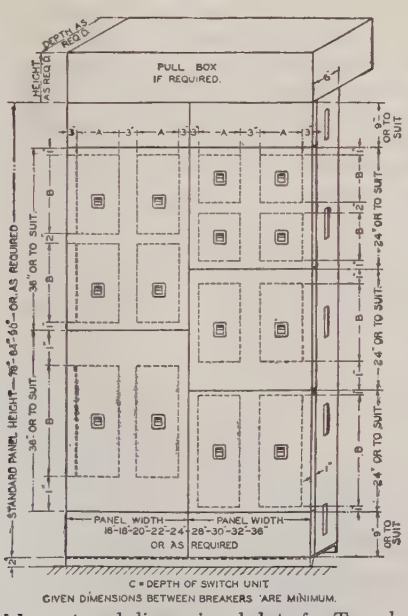


FIG. 125.—Typical layout and dimensional data for Trumbull safety enclosed unit circuit-breaker switchboards.

All Dimensions in Inches

Frame size, amp.	Volts	Poles	*A*	*B*	*C*
50	250	2	2¾	6	3⅜
		3	4⅛	6	3⅜
	600	2	2¾	9 7/16	4 1/16
		3	4⅛	9 7/16	4 1/16
100	250	2	5½	9½	4 1/16
		3	8¼	9½	4 1/16
	600	2	5½	9½	4 1/16
		3	8¼	9½	4 1/16
225	250	2	5½	15½	4⅛
		3	8¼	15½	4⅛
	600	2	5½	15½	4⅛
		3	8¼	15½	4⅛
400 and 600	250	2	8¼	22	5½
		3	8¼	22	5½
	600	2	8¼	22	5½
		3	8¼	22	5½

PANEL BOARDS

86. A panel board as defined by the National Electrical Code is a single panel or a group of panel units designed for assembly in the form of a single panel; including busses and with or without switches and/or automatic overcurrent protective devices for the control of light, heat, or power circuits of small individual as well as aggregate capacity; designed to be placed in a cabinet or cutout box placed in or against a wall or partition and accessible only from the front. A panel board with its enclosing cabinet is sometimes called a panel box. Panel boards provide a compact and convenient method of grouping circuit switching and protective devices at some common point.

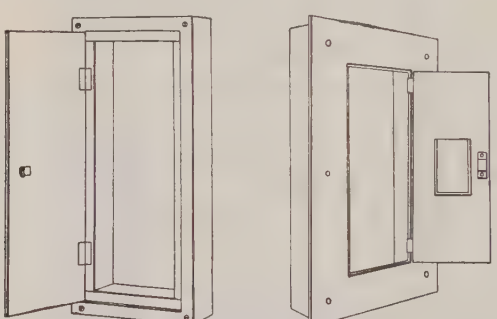


FIG. 126.—Panel boxes.

Panel boxes may be of either the flush or surface type (Fig. 126). The flush type is used with concealed wiring installations and has the advantage of not taking up space in the room by extending beyond the surface of the wall. Surface-type boxes are used for installations employing exposed wiring. The boxes are generally constructed of sheet steel, which must be not less than No. 16 U.S. standard gage in thickness. The steel must be galvanized or covered with some other protective coating to prevent corrosion.

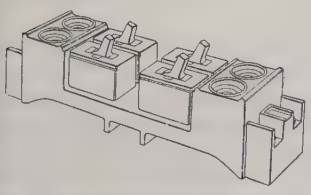
Gutters are provided around the panel boards in panel boxes in order to allow sufficient space for wiring (Figs. 126 and 127). The Code requires that all cabinets which contain connections to more than eight conductors shall be provided with back or side wiring spaces. These wiring spaces must be separated from the panel board or other devices in the cabinet by partitions so that the wiring spaces will be separate closed compartments, unless all wires are led from the cabinet at points directly opposite their terminal connections to the panel board. The

minimum width of gutters required where vertical conductors are deflected upon entering or leaving panel boxes are given as follows:

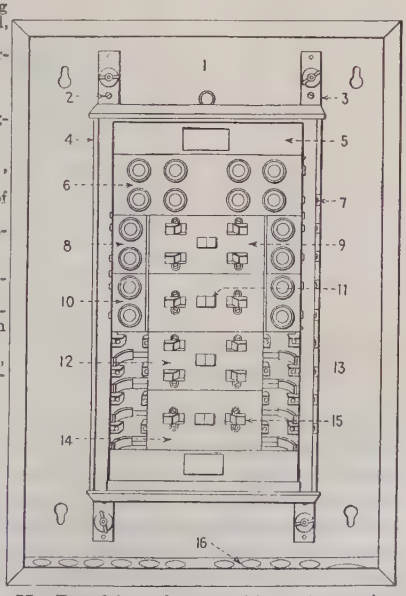
Feeder Size	Minimum Width of Gutter, In.
No. 1	3
No. 1/0 to 200,000 cir. mils	4
211,600 to 500,000 cir. mils	6
600,000 to 900,000 cir. mils	8
1,000,000 to 1,400,000 cir. mils	10
1,500,000 to 2,000,000 cir. mils	12

Feeder Size	Minimum Width of Gutter, In.
No. 1	3
No. 1/0 to 200,000 cir. mils	4
211,600 to 500,000 cir. mils	6
600,000 to 900,000 cir. mils	8
1,000,000 to 1,400,000 cir. mils	10
1,500,000 to 2,000,000 cir. mils	12

1. Galvanized sheet-steel box.
2. Panel adjusting screws.
3. Galvanized channel irons.
4. Removable frame barrier separating wiring gutter from panel board, simplifying panel adjustments.
5. Molded bakelite end section covering main lugs or neutral bar.
6. "Plug fuse only" unit section.
7. Branch circuit terminal screws.
8. Single-fusing, tumbler-switch, plug-fuse type of unit section.
9. Molded bakelite section plates.
10. Double-fusing, tumbler-switch, plug-fuse type of unit section.
11. Index numbers for identification of circuits.
12. Single-fusing, tumbler-switch, cartridge-fuses type of unit section.
13. Wiring gutter.
14. Double-fusing, tumbler-switch, cartridge-fuse type of unit section.
15. Tumbler switches *entirely* removable from front, each enclosed with an individual bakelite cover.
16. Standard knockout arrangement, usually satisfactory for most installations.



I. Unit section of tumbler witches and fuse-plug olders



II. Panel-board assembly, illustrating flexibility of construction

IG. 127.—Typical panel-board construction. (*Trumbull Electric Manufacturing Co.*)

The "trim" of a panel box (Fig. 128) consists of the door and the frame in which it swings. Trims are held to the boxes with screws so they can be readily removed for manipulating wires. The door should close against a rabbet so as to be dusttight.

A panel board consists of a set of copper bus bars, called mains, from which provision is made for tapping off several circuits through overload protective devices and/or switching mechanisms. The provisions for taps generally are built up from unit sections assembled to form the complete board. This plan allows the manufacturers to build a few standard types of unit sections which can be assembled in a great variety of combinations in order to meet the varying requirements of different installations. This results in economy of manufacture and in the greatest flexibility of possible combinations to meet all requirements. Typical panel-board construction is illustrated in Fig. 127. In Fig. 127 several types of unit sections are shown in the same panel board in order to illustrate the different standard types of unit sections and the flexibility of assembly. As a general rule only one or possibly two types of unit sections would be used in a single panel board, although if it were desirable all types could be combined in a single panel board as shown in the figure, since sections of the various types have the same over-all dimensions.

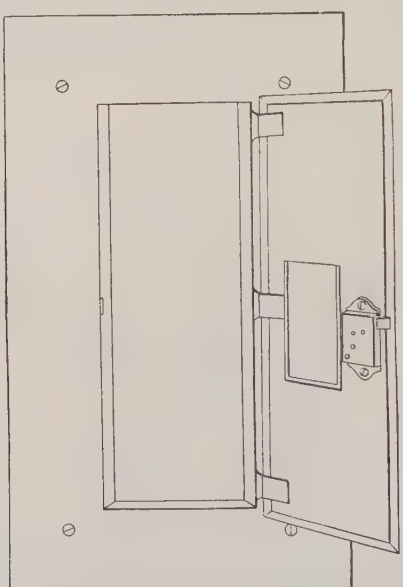


FIG. 128.—Panel-board trim.

87. Lighting panel boxes of modern design are practically always of the dead-front type. Many older boxes of live-front (Fig. 129) construction are, however, in use. In the live-front construction the current-carrying parts of the switches or fuses are exposed when the door of the box is open, while with the safety dead-front construction no live parts are exposed when the door is open.

Lighting panel boards may be obtained with two- or three-wire mains for direct current or single-phase alternating current; with three-wire mains for two-phase alternating current; or with four-wire mains for four-wire, three-phase systems. The mains may be provided with only lugs

for connection to the supply circuit, with fuses in the mains, with both a switch and fuses in the mains, or with a circuit breaker in the mains. Panel boards with only lugs in the mains are shown in Figs. 127, 129, 132, 133, 135, and 136, one with circuit breakers in the mains in Fig. 134, ones with fused switches in Figs. 130 and 146, and one with fuses in the mains in Fig. 131. If a system contains a grounded neutral wire, the main connected to this wire should not be fused. When a circuit breaker is used in the mains, one leg of the breaker may be in series with the grounded neutral, if desired, provided that the breaker

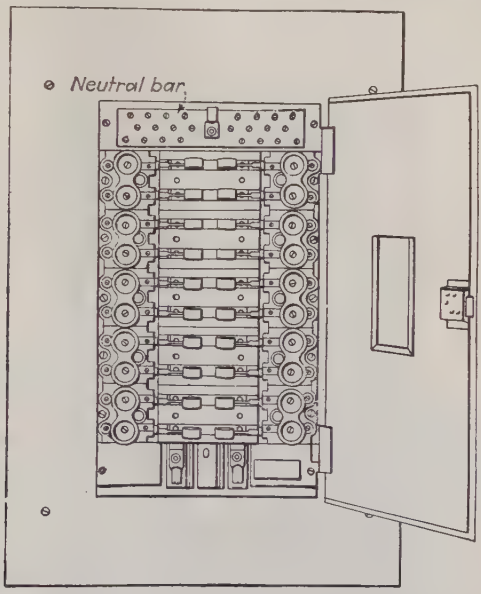


FIG. 129.—Live-front lighting panel board. (*Trumbull Electric Manufacturing Co.*)

pens all legs of the circuit simultaneously. However, when the system ontains a grounded neutral, it is general practice to provide a neutral ar at the top of the panel board. The neutrals of the branch taps and he neutral of the supply are solidly connected to this bar by means of igs or solderless connectors. With this construction there is no neutral us running through the main portion of the panel board. All neutral onductors are carried through the wiring gutter directly to the neutral bar see Figs. 129, 130, 131, and 135). When a fused switch is desired in ne mains, the switching fuse (see Sec. **97** for description) provides, in ompact construction, protection to the panel and a means of disconnect- ig the complete panel from the supply.

The National Electrical Code requires overcurrent protection to be provided in the mains on panel boards supplying lighting and/or appliance branch circuits when the overcurrent protection of the conductors supplying the panel board is greater than 200 amp. The rating of the overcurrent devices protecting the panel board should be in accordance with the load on the panel board and must not exceed the rating of the mains

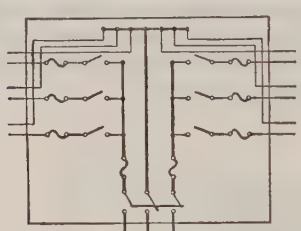


FIG. 130.—Diagram of lighting panel board with three-wire mains and two-wire branches; solid-neutral, single-fusing in branches; switch and fuses in mains; switches in branches.

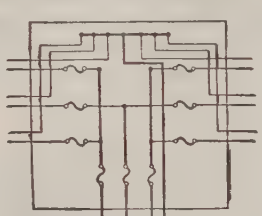


FIG. 131.—Diagram of three-phase, four-wire lighting panel board with two-wire, single-phase branches; fuses only in mains; fuses only in branches.

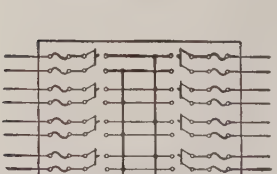


FIG. 132.—Diagram of lighting panel board with two-wire mains and two-wire branches; lugs only in mains; switches and double fusing in branches.

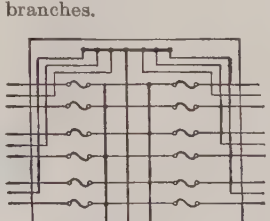


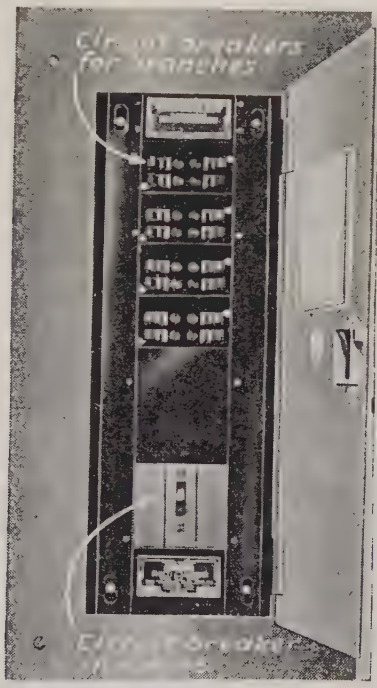
FIG. 133.—Diagram of lighting panel board with three-wire mains and three-wire branches; lugs only in mains; fuses only in branches.

of the panel board. The method of computing loads on panel boards is discussed in Div. 3.

The branch lighting circuits are generally two wire, although in some cases three-wire branches are employed. Branches may be provided with only fuses (Figs. 131, 133, and 146), switches and fuses (Figs. 127, 130, 132, and 135), or circuit breakers (Figs. 134, 135, and 136). Switches when used are practically always of the tumbler type. On systems with a permanently grounded neutral the two-wire branch circuits are protected by a single fuse or circuit breaker in the ungrounded wire. In

some cases the inspection department may require fuses or circuit breakers in both wires. Two-wire branches on ungrounded systems must be provided with fuses or circuit breakers in both wires. When fuses are used in panel boards, they may be of the plug-fuse, cartridge-fuse, or cartridge-fuse-in-plug-case types. Typical diagrams of connection for lighting panels are shown in Figs. 130 to 133 and 135 and 136.

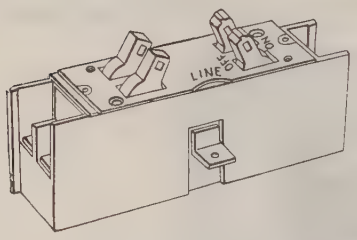
88. Lighting panel boards with breakers in the branches (Fig. 134) are made in three types. Two of these types are assemblies of multibreaker



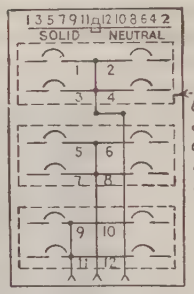
g. 134.—Circuit-breaker type of lighting panel board. (*Trumbull Electric Manufacturing Co.*)

its. The difference in them is that the multibreaker units of one type ntain four single-pole breakers with two breakers on each side of the nel board mains (Fig. 135, I), while the units of the other type consist only two single-pole breakers, both located on the same side of the ins (Fig. 135, II). In both types it is possible to employ a common ndle for two breakers, thus converting them into double-pole breakers. e two breaker units allow for greater flexibility in the arrangement of e circuits. Narrow-type panels, called the column type, are made of

assemblies of the two breaker units with all units located on the same sid of the mains as shown in Fig. 136. This type was especially designed fo mounting in the web of H columns in factory buildings. They are mad in two widths for location on 10- and 8-in. H beams, respectively. Owin

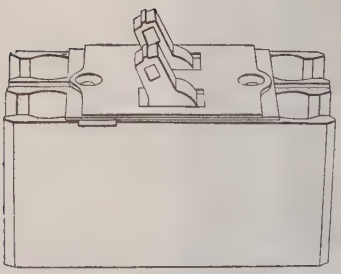


(a)-Unit section

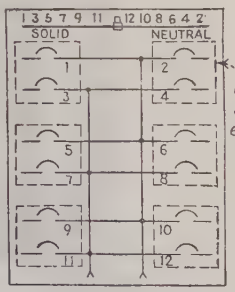


(b)-Panel with four-wire mains and two-wire branches Lugs only in mains

I-Four single pole breaker section



(a)-Unit section



(b)-Panel with three-wire mains and two-wire branches Lugs only in mains

II-Two single pole breaker section

FIG. 135.—Circuit-breaker panel boards with multi-breaker unit section (*Trumbull Electric Manufacturing Co.*)

to the limited space in these column panels, they are generally provide with a trough extension and pull box as shown in Fig. 144. The mann in which these multibreaker units are assembled to form a complete pan board is shown in Figs. 135*b*, 136, 141, and 142. The breakers can supplied in 15-, 20-, 25-, 35-, and 50-amp. capacities.

The third type of breaker panel board consists of an assembly of individual breaker units mounted on a heavy galvanized-steel back plate. The breakers are available in 15-, 20-, 25-, 35-, and 50-amp. capacity in

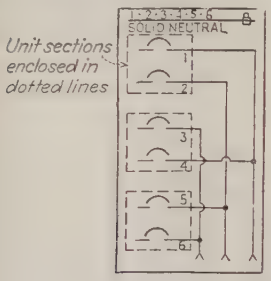


FIG. 136.—Arrangement of two-breaker sections for narrow-type panel boards; four-wire mains with two-wire branches.

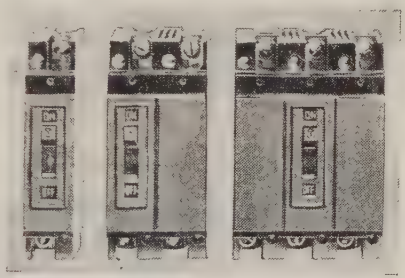


FIG. 137.—Single, two-, and three-pole, 50-amp. frame-size circuit breakers for panel-board mounting. (*Trumbull Electric Manufacturing Co.*)

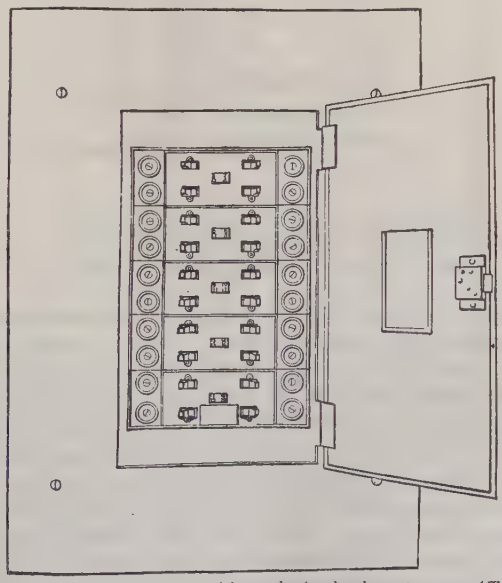


FIG. 138.—Dead-front lighting panel board, single-door type. (*Trumbull Electric Manufacturing Co.*)

ne-, two-, or three-pole construction (Fig. 137). The breakers are so esigned that the width of the breaker housing is proportional to the umber of poles so that a three-pole breaker will just fit in the space

required for three single-pole breakers. This allows for the greatest flexibility in the original arrangement of circuits or in alterations in circuits to accommodate changes in an electrical wiring system.

89. Lighting panel boards with switches and fuses in the branches are generally constructed of an assembly of molded bakelite sections. Each

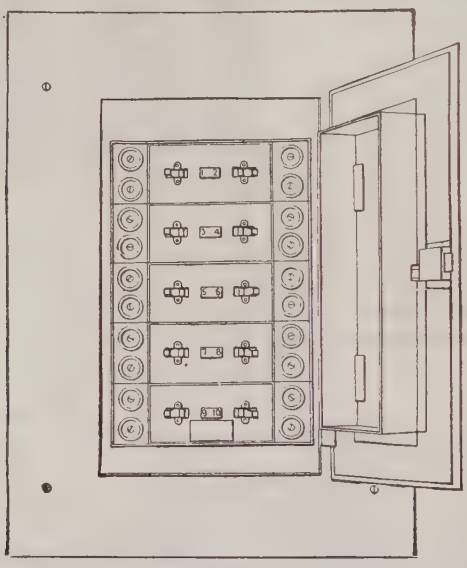


FIG. 139.—Dead-front lighting panel board, door-in-door type; both doors open. (*Trumbull Electric Manufacturing Co.*)

section generally consists of four 30-amp. tumbler switches with fuse holders for either plug or cartridge fuses. Typical construction is shown in Fig. 127. Two types of trim construction are available, the single door and the door-in-door. In the single-door type (Fig. 138), opening of the door gives access to both the handles of the dead-front switches and the fuses. With the door-in-door construction, opening of the inner door (Fig. 140) gives access only to the handles of the branch switches. Opening of both doors (Fig. 139) gives access to both the switch handles and the fuse compartment. The door-in-door construction is especially advantageous where it is desirable to have the replacement of fuses under the control of only qualified persons.

90. Panel boards with only fuses in the branches are generally constructed of molded bakelite sections, similar to switch and fuse panels except that each section generally consists of fuse holders without any switches, as shown in Figs. 127 and 146.

91. Narrow-type panels of either the switch and fuse or only fuse type are available for mounting in restricted spaces. Assembly of such panels is shown in Figs. 147 and 148.

92. The maximum number of branch circuits in a panel board must not exceed 42 where one overcurrent protective device per circuit is used or 21 where two overcurrent protective devices per circuit are employed.

93. The size of the mains in panel boards is very important. The

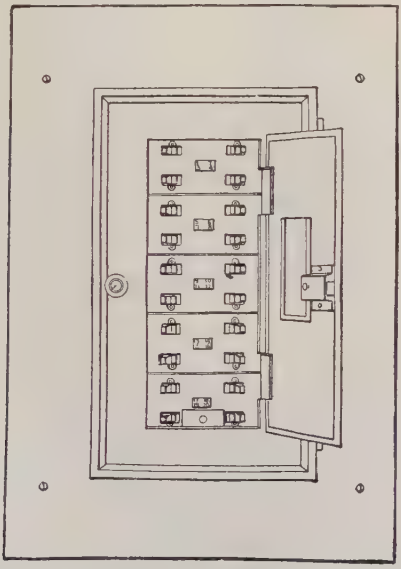


FIG. 140.—Dead-front lighting panel board, door-in-door type; inner door open. (*Trumbull Electric Manufacturing Co.*)

ampere capacity of the mains should be determined from the load that the panel will supply, by the methods given in Div. 3. If the standard size furnished by the panel-board manufacturer is less than the calculated load, the size of main required should be specified in the order.

94. Lighting Panel-board Dimensions.—It is often advantageous to know the space that will be required by a panel board. The following information taken from one manufacturer's line will be found helpful when manufacturers' catalogues are not available. The standard depth of panel boxes is 4½ in. inside and 4¾ in. outside. All panel boards with the mains equipped with only lugs or with switching fuses will fit in the standard boxes. When the mains are equipped with circuit breaker, the box may have to be deeper than 4½ in. inside, the inside dimensions depending upon the size of mains as shown in the table at the top of page 438.

Capacity of mains, amp.	Inside depth of box, in.		
	Four-breaker unit sections	Two-breaker unit sections	One-breaker unit sections
50	4½	4½	4½
100	4½[a]	5¼	5¼
200	4½[a]	5¼	5¼
225	...	...	6

[a] 5¼ for panels with two- or four-wire mains.

94A. The height and width required for a panel box can be estimated from the following instructions and Figs. 141 to 148. The widths required are shown on the figures for the different types of panels. The height required will be the sum of the following dimensions:

1. Number of unit sections times width of unit as given in the figures.
2. Allowance for top and bottom assembly of panel board as given in the figures.

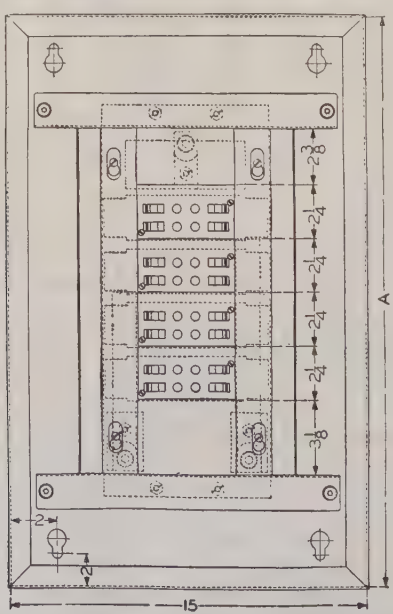


FIG. 141.—Details of construction and dimensional data for panel boards built up from unit sections of the four-breaker type. All dimensions in inches; dimension *A* indicates height of box required.

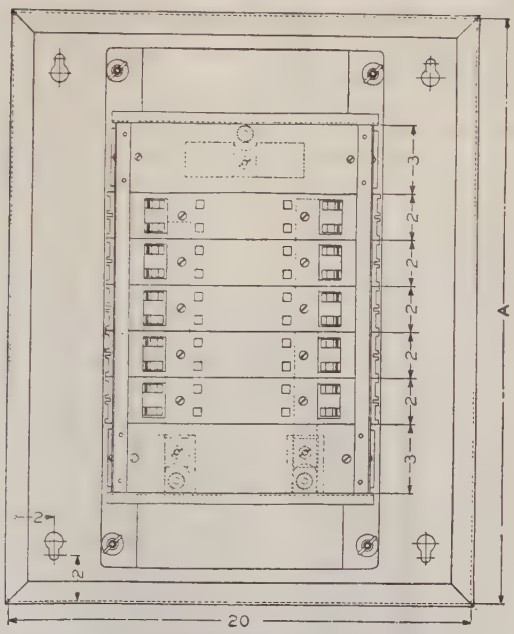


FIG. 142.—Details of construction and dimensional data for panel boards built up from unit sections of the two-breaker type. All dimensions in inches; dimension *A* indicates height of box required.

Standard Box Dimensions

Heights in Inches for Following Widths

Width, 12½ in.	Width, 15 in.	Width, 20 in.	Width, 15 in.	Width, 20 in.
12	18	16½	57	49½
15	21	19½	60	52½
18	24	22½		55½
21	27	25½		58½
24	30	28½		61½
27	33	31½		64½
30	36	34½		67½
33	39	40½		70½
36	42	43½		73½
39	45	46½		

NOTE.—All dimensions are for inside of box. Outside dimensions will be greater by ¼ in.

3. Space for main fused switch or circuit breaker when used. Allow 9 in. for a switching fuse up to 100 amp. size; 12 in. for a switching fuse of 200 amp. size; 18 in. for circuit breaker.

4. Two times gutter width. Allow 4 in. for width of gutter unless greater width would be required by Sec. **86**.

The height of the box designated by dimension *A* in the figures will be the standard-sized box that will accommodate the above-estimated required height.

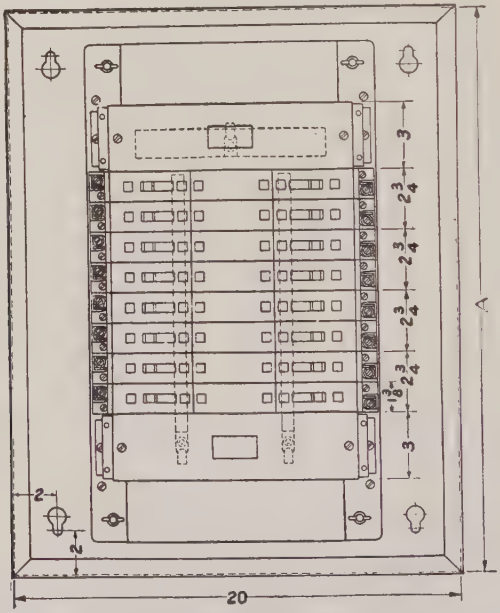


FIG. 143.—Details of construction and dimensional data for panel boards built up from individual breaker units. All dimension in inches; dimension A indicates height of box required.

Example.—Estimate dimensions of a panel box for an eight-circuit panel with switch and fuses in branches and with mains provided with a switching fuse. Single fusing is to be employed. The panel has three-wire mains and two-wire branches. Capacity of mains is 100 amp.

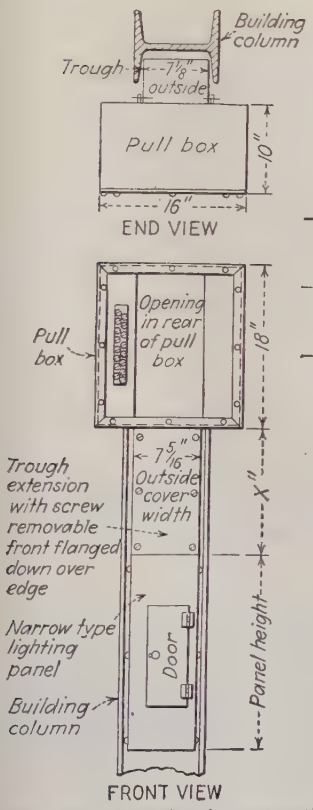
Solution.—From Sec. **93** the inside depth will be 4½ in. Refer to Fig. 145 for this type of panel board. The width will be 20 in.

An eight-circuit, single-fused panel will require two unit sections

Estimating height:

1. Space for unit sections = 2 × 3	=	6 in
2. Allowance for top of panel board	=	3 in
3. Allowance for bottom of panel board	=	3 in.
4. Space for main switching fuse	=	9 in.
5. Space for gutter = 2 × 4	=	8 in.
		29 in.

A standard-sized box to accommodate the required 29 in. would be 31½ inches high. It might be possible to use a 28½-in. box by reducing each of items 2, 3, and 4 by a fraction of an inch.



PULL BOX
Dimensions in Inches

Height	Width	Depth
18	16	10

TROUGH EXTENSIONS
Length *X* in Inches

36
46
56
66
76
86
96
106
116
126

FIG. 144.—Details of construction and dimensional data for narrow-column type of panel board built up from unit sections of the two-breaker type.

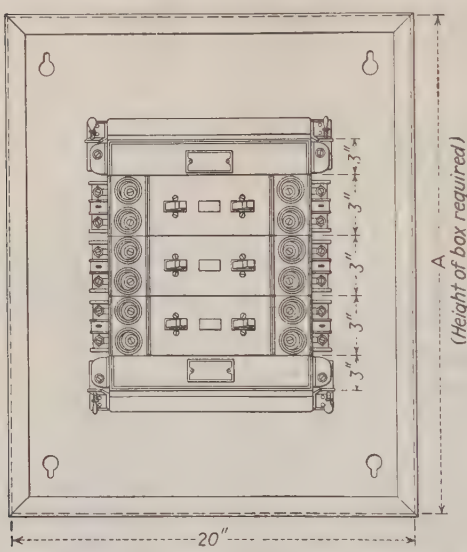


FIG. 145.—Details of construction and dimensional data for panel boards built up from unit sections of the four-single-pole fused-switch type.

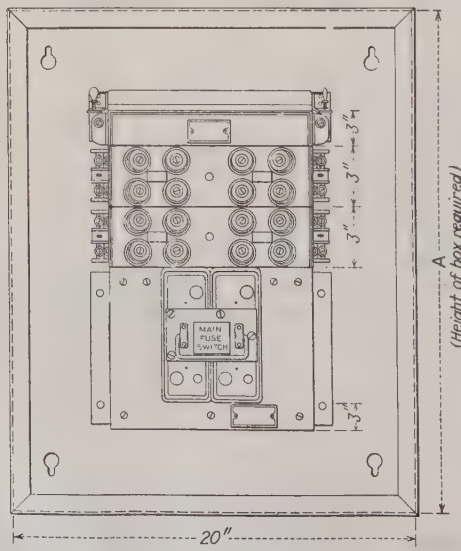


FIG. 146.—Details of construction and dimensional data for panel boards built up from unit sections of the eight-fuse-only type.

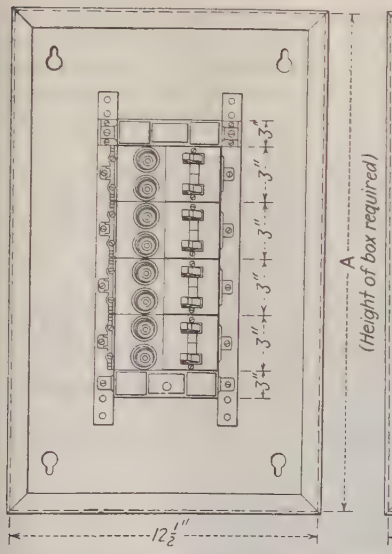


FIG. 147.—Details of construction and dimensional data for narrow panel boards built up from unit sections of the two-single-pole fused-switch type.

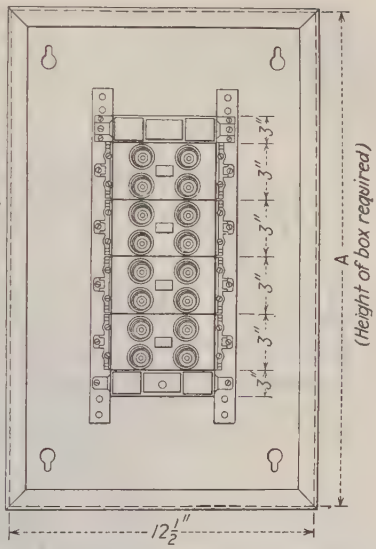
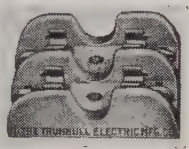


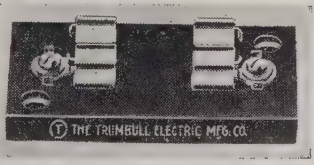
FIG. 148.—Details of construction and dimensional data for narrow panel boards built up from unit sections of the four-fuse-only type.

I. Two-pole, double-branch porcelain holder for cartridge fuses



II. Two-pole, single-branch porcelain holder for cartridge fuses

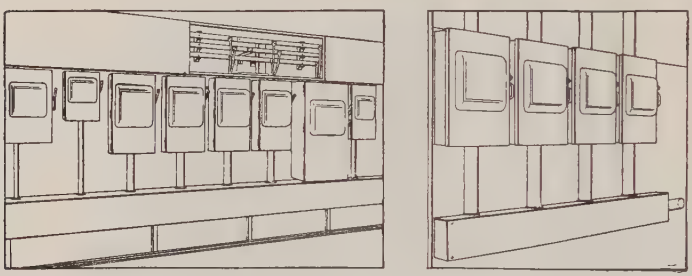
III. Two-pole, single-branch porcelain holder for plug fuses



IV. Single-pole, single-branch slate base holder for cartridge fuses

FIG. 149.—Fuse cutout blocks (fuse holders). (*Trumbull Electric Manufacturing Co.*)

95. Power Panel Boards.—Several different methods are employed at the distribution centers of power circuits for the mounting of protective and switching equipment. A very inexpensive method is to mount cutout blocks (Fig. 149) or cutout blocks with switches inside a sheet-metal



I II

FIG. 150.—Distribution centers consisting of a group of safety switches and auxiliary gutters.

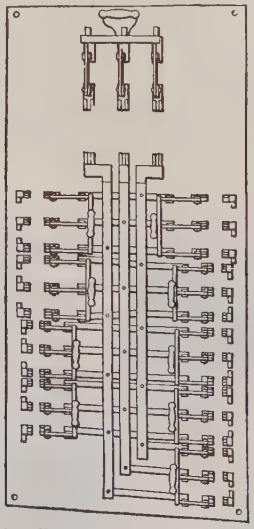


FIG. 151.—Live-front power panel board.

box. This method does not produce a very neat or safe installation. If a box contains cutouts for more than four circuits, it must be provided with a wiring gutter, unless the wires leave the box directly opposite their terminal connections.

A better method is to employ a regular power panel or a group of individual safety switches or circuit breakers connected to the supply

hrough a wiring gutter (Fig. 150). Regular power panels provide a very ompact arrangement of the equipment requiring a relatively small nounting space and producing a very neat-appearing installation. Power panel boards may be obtained from the various panel-board manu- acturers in either live- or dead-front types of construction. Their general

Fig. 152.—Typical Swing-Wa panel board with single-branch units. ouble-branch units are available in 30- and 60-amp., 230- to 575-volt, a-c and 0-amp., 230-volt, a-c capacities. (*Trumbull Electric Manufacturing Co.*)

nstruction is quite similar to lighting panel boards on a larger scale. he switches and mains except for branch circuits supplying very small otors must have greater current-carrying capacities and be of more gged construction than is required for lighting panels. Where the pacity of any circuit fed from the panel is not greater than 50 amp. a ndardized panel board of single breaker units of exactly the same con- ruction as the circuit-breaker lighting panel boards of Sec. **87** may be

employed. For circuits of greater capacity the size of branch motor circuits cannot be standardized to one or two sizes as in the case of branch lighting circuits but must be of the size required by the ratings of the individual motors fed from the panel. A power panel must, therefore, provide switches and fuses or circuit breakers of several different sizes. For this reason power panels cannot be standardized to the extent that lighting panel boards are, but each panel must be built to meet the requirements of size and number of branch circuits required by the particular installation. A power panel board of the live-front type is shown in Fig. 151. Only the panel board is shown in the figure. The panel

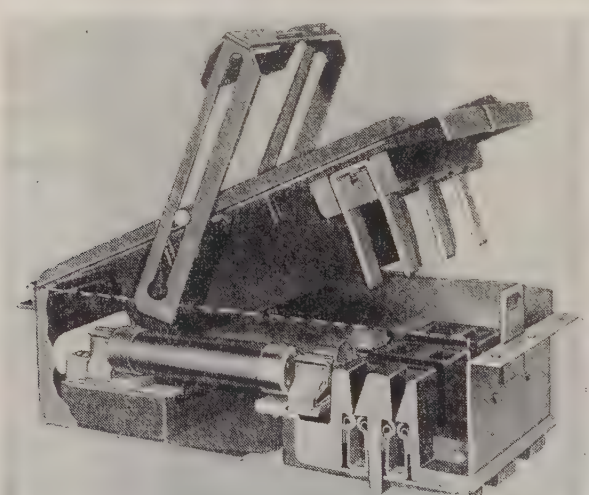


FIG. 153.—Cutaway view of Swing-Wa unit showing door partly open and stabs disengaged. (*Trumbull Electric Manufacturing Co.*)

board would be enclosed in a panel box with wiring gutters similar to lighting panel boxes.

Safety dead-front power panel boxes are available in three general types of construction: special indicating fused-switch units, switching fuse units, and circuit-breaker units.

96. A power panel board using special indicating fused-switch units is shown in Fig. 152. This panel board is built up of individually steel-enclosed fused-switching units assembled in a sheet-metal panel box. The construction of the unit for each branch circuit is shown in Fig. 153. The door of each unit supports the switching contacts. When the door is opened, it disengages the switch stabs and entirely disconnects the circuit. Full safety and protection is provided since no current-carrying parts are accessible to the operator with the door closed, and when the door is

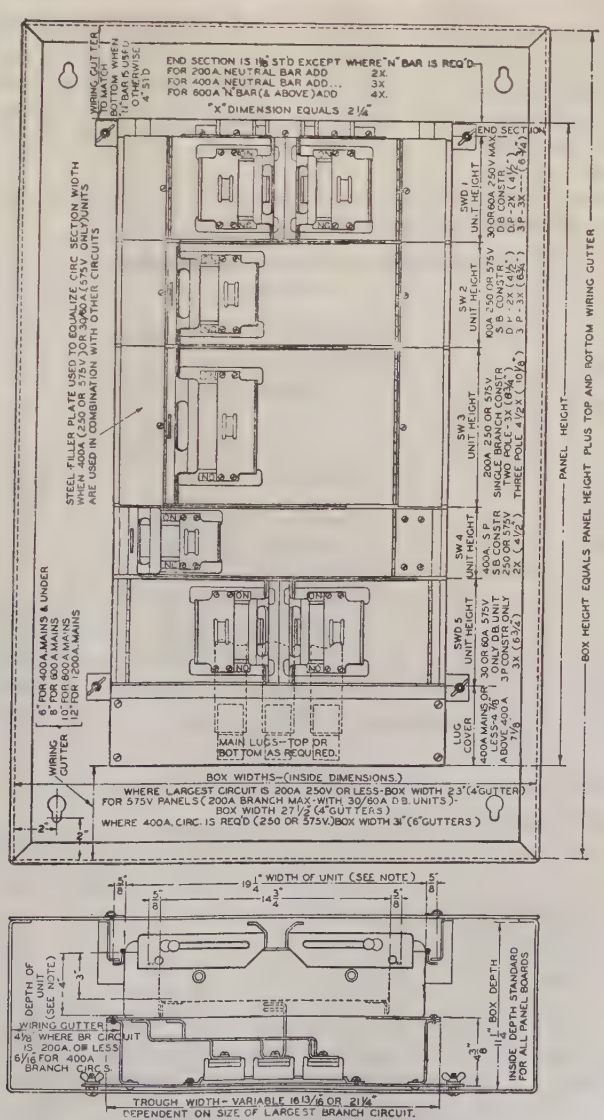


Fig. 154.—Construction and dimensional data for Trumbull Swing-Wa power-distribution panel boards.

opened for changing of fuses the circuit is thereby disconnected from the supply. With the door open, the mechanism may be thrown in the "off" or "on" position and the door reclosed. With the door closed, indication is given on the front of the unit telling if the switch stabs are in the "on" or "off" position. The switches are rated Type A, motor-circuit switches.

The space required for a complete panel board may be easily estimated from Fig. 154 and the following data and instructions:

Dimensional Tables for Box Heights

($X = 2\frac{1}{4}$ in.)

TABLE 1.—SWING-WA UNIT HEIGHTS

230 Volts A.C., 250 Volts D.C.

Amp.	Height of sections			
	2 pole	Type	3 pole	Type
60–60[a]	2X	SWD1-222	3X	SWD1-322
100–100[a]	2X	SWD5-223	3X	SWD5-323
100	2X	SW2-223	3X	SW2-323
200	3X	SW3-224	4½X	SW3-324
400	4X	SW4-225	6X	SW4-325
575 Volts A.C.				
30–30[a]	2X	SWD5-261	3X	SWD5-361
60–60[a]	2X	SWD5-262	3X	SWD5-362
100	2X	SW2-263	3X	SW2-363
200	3X	SW3-264	4½X	SW3-364
400	4X	SW4-265	6X	SW4-365

[a] Double branch units.

TABLE 2.—HEIGHT ADDITIONS

Capacity of mains, amp.	For neutral bars (end section)	Wiring gutter (bottom)[a]	Lug cover
No neutral	1⅛ in.	6	4⅞
200	2X	6	4⅞
400	3X	6	4⅞
600	4X	8	7⅛
800	....	10	7⅛
1,200	....	12	7⅛

[a] Wiring gutter at top to match bottom when N bar is used; otherwise 4 in. is standard

Estimating Box Dimensions

Style of Units and Dimensional Data. STYLE 1.—Double branch 30 or 60 amp.; 230 volts a.c. or 250 volts d.c.; 3 in. deep, 14¾ in. wid (requires box 23 in.).

STYLE 2.—Single branch; 30, 60, or 100 amp., 230 volts a.c., 250 volts d.c., or 575 volts a.c.; 4 in. deep, 14¾ in. wide (requires box 23 in. wide).

STYLE 3.—Single branch; 200 amp.; 230 volts a.c.; 250 volts d.c., or 575 volts a.c.; 4 in. deep, 14¾ in. wide (requires box 23 in. wide).

STYLE 4.—Single branch, 400 amp.; 230 volts a.c., 250 volts d.c., or 575 volts a.c.; 4 in. deep; 19¼ in. wide (requires box 31 in. wide).

STYLE 5.—Double branch; 30 or 60 amp.; 575 volts a.c.; 30, 60, or 100 amp.; 230 volts a.c., 250 volts d.c.; 4 in. deep; 19¼ in. wide. (If used in combination with maximum of 200 amp. unit or less, requires box 27½ in. wide; over 200 amp. requires box 31 in. wide.)

DEPTH.—11¼ in. for all panel boards.

WIDTH.

Circuit, amp.	Volts	Width, in.	Gutters, in.
Up to 200	250	23	4
	575	27½	4
Over 200	Any	31	6

HEIGHT.—Add up the number of X's or inches for each of the following as the case may be (X dimensions may be converted to inches by multiplying by 2¼).

1. Wiring gutters (top), Table 2.
2. End section, Table 2.
3. X height of individual circuits (convert to inches by multiplying by 2¼), Table 1.
4. Lug cover, Table 2.
5. Wiring gutter (bottom), Table 2.
6. Add total number of inches for close approximation of box height.

Typical Examples. *Example* 1.—3/3 wire, three-phase, 250-volt panel board with 400-amp. main lugs and the following branch circuits: two 30-amp., three-pole; two 60-amp., three-pole; one 100-amp., three-pole; and one 200-amp., three-pole.

Wiring gutter bottom		6 in.
Lug cover		4⅞ in.
One 200-amp., three-pole	4½X	
One 100 amp., three-pole	3X	
Two 60 amp., three-pole	3X	
Two 30 amp., three-pole	3X	
	13½X =	30¼ in.
End section		1⅛ in.
Wiring gutter top		4 in.
Box height		46¼ in.
Box depth		11¼ in.
Box width		23 in.

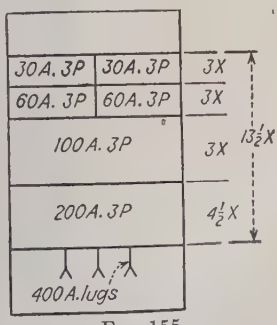


FIG. 155.

Example 2.—Single-phase, 3/2 wire, 250-volt panel board with 400-amp. main lugs and the following branch circuits: two 30-amp., two-pole; two 60-amp., 2-pole; one 100-amp., two-pole and one 200-amp., two-pole.

Wiring gutter bottom	6 in.
Lug cover	4⅞ in.
One 200 amp., two pole	2X
One 100 amp., two pole	2X
Two 60 amp., two pole	2X
Two 30 amp., two pole	3X
	9X = 20¼ in.
End section (3X)	6¾ in.
Wiring gutter top	6 in.
Box height	43⅞ in.
Box depth	11¼ in.
Box width	23 in.

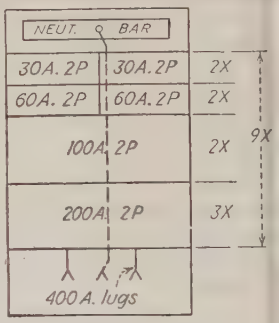


FIG. 156.

97. Power panel boards using switching-fuse units sometimes called fuse-puller switches, (Figs. 157 and 158) consist of fuses mounted on a safety dead-front removable cap (Fig. 159), fitted with contact jaws which

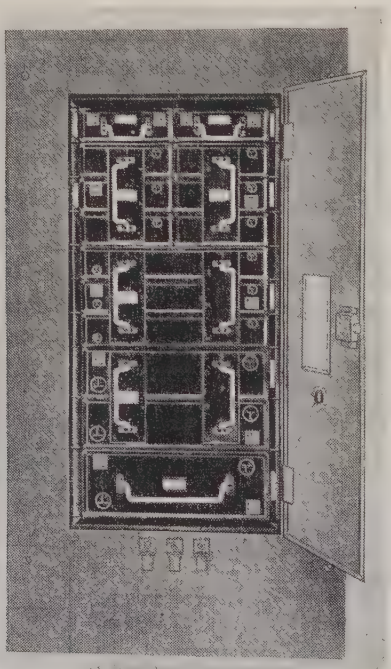


FIG. 157.—Power-distribution panel board with switching fuse units (Trumbull Converti-fuse panel).

engage with stationary stabs (Fig. 160) supported on the panel-board structure. With this construction the fuses may be removed without danger of contact with any live parts. When it is desired to leave the circuit open, the fuse-holder cap may be removed, turned through 180 deg., and reinserted. With the holder inserted in this position, the

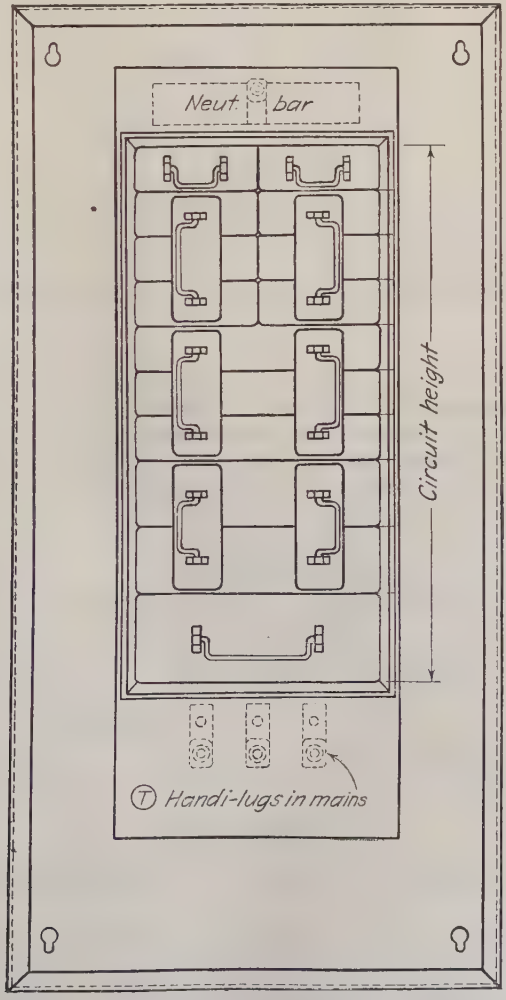


FIG. 158.—Assembly of Trumbull Converti-fuse power-distribution panel board.

circuit is open. Sizes up to 200 amp. are rated as general-purpose switches and may be used for interrupting the current of the circuit. Larger sizes are rated as disconnecting switches and should not be used for interrupting the current of the circuit. These panels have the

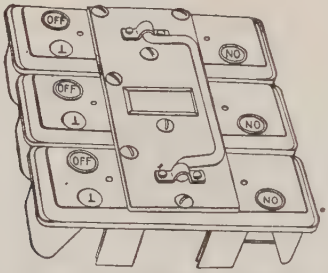


FIG. 159.—Safety-fuse holder for safety-fuse power panel board. (*Trumbull Electric Manufacturing Co.*)

advantage of very compact, dead-front, safety enclosed construction giving wide flexibility in adaptation for branches of different capacities. The switching fuse units are rated as general-purpose switches up to the 200-amp size. Above 200 amp. they are only rated as disconnecting switches and should not be used for interrupting the current of a circuit.

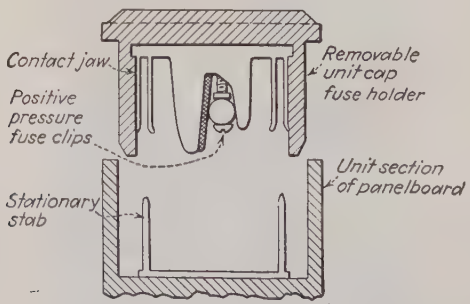


FIG. 160.—Construction of a switching fuse (Trumbull Converti-fuse).

Panels using this general construction are sold under different trade names such as Converti-fuse, Saf-to-Fuse, etc.

The space required for a complete Converti-fuse panel board may be easily estimated from Fig. 161 and the following data and instructions.

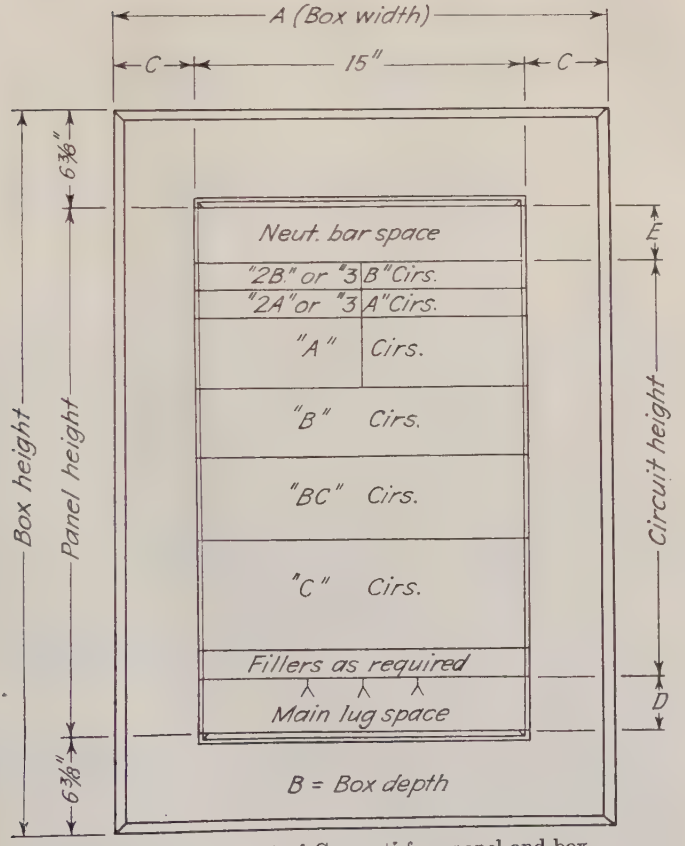


FIG. 161.—Layout of Converti-fuse panel and box.

97A. Estimating Box Size of Converti-fuse Panel Boards

TABLE 1

Maximum *C/F* unit	*A* dimension (width), in.	*B* dimension (depth), in.	*C* dimension (side wiring gutter), in.
200 amp. and under	22	6¼	3½
400 amp	26	7¼	5½
600 amp. (250 volts only)	26	7¼	5½

TABLE 2
$X = 2\frac{3}{8}$ in.

Main capacity, amp.	D dimension (main lug space)	E dimension[a] (neutral bar space)	
		Three-wire, single-phase	Four-wire, three-phase
200	2X	2X	2X
400	2X	2X(1)	2X
600	3X	2X(2)	4X
800[b]	3X	2X(2)	4X
1,200[c]	4X	3X	4X

[a] Neutral bars limited to a maximum of one 400-amp. main lug and six 200-amp. or ten 100-amp., or twelve 50-amp. branch lugs. For increased capacity of main neutral lug or increase in quantity of branch lugs, add to the number of X's given under E:

(1) 400-amp. neutral bar..... 1X
(2) 600- or 800-amp. neutral bars..... 1X

[b] Twin lugs standard for two 500,000-cir. mil cables per phase.
[c] Twin lugs standard for two 1,000,000-cir. mil cables per phase.

TABLE 3.—UNIT HEIGHTS
$X = 2\frac{3}{8}$ in.

Type of unit	Capacity, amp.	Volts	Type branches	Number of poles		
				One	Two	Three
2B	30	250	DB	...	1X	
3B	30	250	DB	...	...	1X
2A	30/60	250	DB	...	1X	
3A	30/60	250	DB	...	...	1X
A	30/60/100	250	DB	1X	2X	3X
A	30/60	575	DB	...	2X	3X
B	200	250	SB	1X	2X	3X
B	100	575	SB	...	2X	3X
BC	200	575	SB	...	3X	$4\frac{1}{2}X$
C	400/600	250	SB	2X	4X	6X
C	400	575	SB	...	4X	6X

TABLE 4.—BOX HEIGHT
$X = 2\frac{3}{8}$ in.

Panel Height Total X's	Box Height,[a] In.
5	24⅝
8	31¾
11	38⅞
14	46
17	53⅛
20	60¼
23	67⅜
26	74½
29	81⅝
32	88⅜
35	95⅞

[a] If box size exceeds 81⅝ in., a two-section panel should be considered to reduce height.

97B. Estimating Box Size. DEPTH.—See item *B*, Table 1.

WIDTH.—See item *A*, Table 1.

HEIGHT.—1. Neutral bar space when required; see item *E*, Table 2.

2. Total circuit height, including main *C/F* unit when required; make layout sketch and refer to Table 3 for individual circuit heights. Note double-branch construction on Type 2B, 3B, 2A, 3A, and A circuits.

3. Main lug space; see item *D*, Table 2. Omit if main unit is required.

Panel height is the sum of the *X*'s (items 1 through 3) plus blank fillers required to agree with total *X*'s given in Table 4.

Box height in inches (based on panel height in *X*'s) is selected from Table 4.

Example 1.—3/3 wire, three-phase, 250-volt panel board with 400-amp. mains and the following branch circuits:

Two 30-amp., three-pole, 3B.....	1*X*
Two 100-amp., two-pole, A.....	2*X*
Two 100-amp., three-pole, A.....	3*X*
One 200-amp., three-pole B.....	3*X*
400-amp. main lugs.....	2*X*
	11*X*

Use box 38⅞ in. high, 22 in. wide, and 6¼ in. deep.

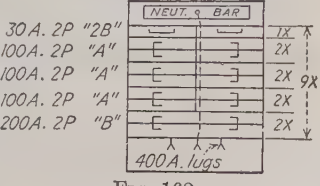


FIG. 162.

98. Power panel boards using circuit breakers in the branches (Fig. 163) are made in sectionalized construction so that each breaker is a removable unit. This sectionalized construction and standardization of breaker dimensions permits great flexibility in the design and convertibility of these panels to meet changing circuit conditions. Each breaker is safety enclosed in its individual composition or bakelite case, providing dead-front complete safety construction.

FIG. 163.—Circuit-breaker type of power-distribution panel board. (*Trumbull Electric Manufacturing Co.*)

The space required for a circuit-breaker power panel board may be easily estimated from Fig. 164 and the following data and instructions:

98A. Estimating Box Size of Convertible Circuit-breaker Distribution Panel Boards

TABLE 1

Maximum breaker frame size	*A* dimension (width), in.	*B* dimension (depth), in.	*C* dimension (side wiring cutter), in.
225 amp. and under	28	9½	4
400 amp.	35	11½	7½
600 amp.	40	11½	10

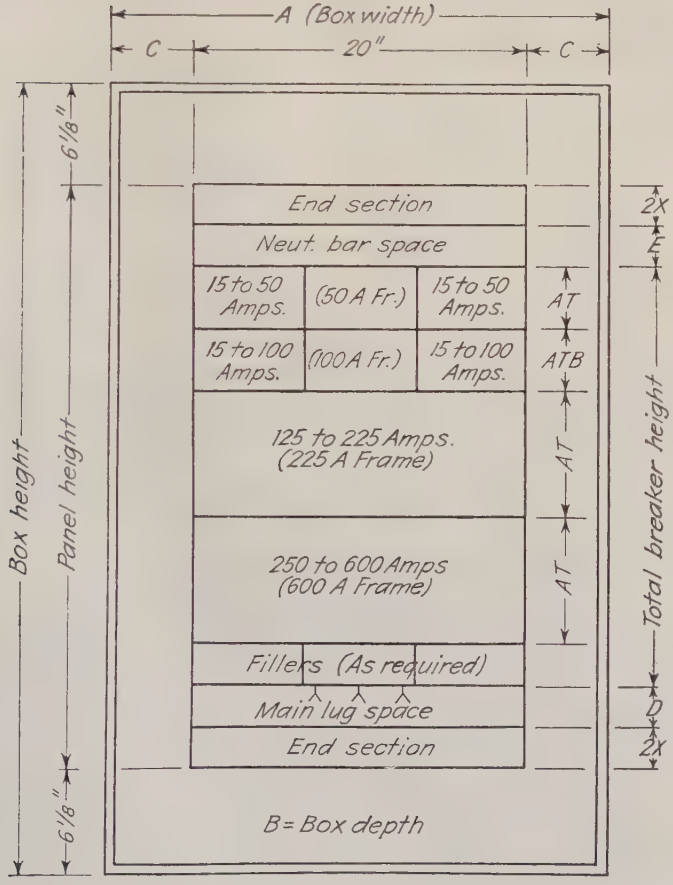


Fig. 164.—Convertible circuit-breaker panel and box.

TABLE 2
$X = 1\frac{3}{8}$ in.

Main capacity, amp.	D dimension (part of lug space)	E dimension[a] (neutral bar space)	
		Three-wire, single-phase	Four-wire, three-phase
225	2X	2X	2X
400	2X	2X (1)	2X (1)
600	4X	2X (2)	4X
800[b]	4X	2X (2)	4X
1,200[c]	6X	2X (3)	6X

[a] Neutral bars limited to a maximum of one 400-amp. main lug and six 200-amp. or ten 100-amp., or twelve 50-amp. branch lugs. For increased capacity of main neutral lug or increase in quantity of branch lugs, add to the number of X's given under E:

(1) 400-amp. neutrals..... 2X
(2) 600- or 800-amp. neutrals (with branch lugs not over 600 amp)... 2X
(3) 1,200-amp. neutral (with branch lugs not over 600 amp)..... 2X

[b] Twin lugs standard for two 500,000-cir. mil cables per phase.
[c] Twin lugs standard for two 1,000,000-cir. mil cables per phase.

TABLE 3.—BREAKER HEIGHTS
$X = 1\frac{3}{8}$ in.

Type of breaker	Frame size breaker, amp.	Number of poles		
		One	Two	Three
AT	50	X	2X	3X
ATB	100	.....	2X	3X
AT	225	.....	4X	6X
AT	600	.....	6X	6X

TABLE 4.—BOX HEIGHT

$X = 1\frac{3}{8}$ in.

Panel Height Total X's	Box Height,[a] In.
15	32⅞
18	37
21	41⅛
24	45¼
27	49⅜
30	53½
33	57⅝
36	61¾
39	65⅞
42	70
45	74⅛
48	78¼
51	82⅜

[a] When total panel height exceeds $51X$, divide into two or more sections, balancing utilization of panel height and ampere capacity in each section.

98B. Convertible Circuit-breaker Panel Boards. Estimating Box Size. DEPTH.—See item *B*, Table 1.

WIDTH.—See item *A*, Table 1.

HEIGHT.—1. End section spaces (top and bottom of panel) equal $4X$ total.

2. Neutral bar space when required; see item *E*, Table 2.

3. Total breaker height including main circuit breaker when required; make layout sketch and refer to Table 3 for individual breaker heights. Note double-branch construction on 50- and 100-amp. frame breakers.

4. Portion main lug space; see item *D*, Table 2. Omit if main lug is required.

Panel height is the sum of the X's (items 1 through 4) with blank fillers added to make the height a multiple of $3X$.

Box height, in inches (based on panel height in X's) is selected from Table 4.

Example 1 (Fig. 165).—Three-phase, three-wire, 250-volt panel board with 400-amp. main lugs and four 50-amp., three-pole circuits, two 100-amp., three-pole circuits and one 225-amp., three-pole circuit.

End section spaces	$4X$
Two 50-amp., three-pole breakers	$3X$
Two 50-amp., three-pole breakers	$3X$
Two 100-amp., three-pole breakers	$3X$
One 225-amp., three-pole breaker	$6X$
Main lug space	$2X$
Total	$21X$
Total box height	41⅛ in.
Box width	28 in.
Box depth	9½ in.

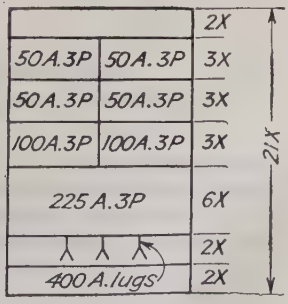


FIG. 165.

Example 2 (Fig. 166).—Single-phase, 3/3 wire, 250-volt panel board, 400-amp. main lugs with the following branch circuits: four 50 amp., three-wire; two 100-amp., three-wire; and one 225 amp., three-wire.

End section spaces	4X
Neutral bar space	2X
Two 50-amp. two-pole breakers	2X
Two 50-amp. two-pole breakers	2X
Two 100-amp. two-pole breakers	2X
One 225-amp. two-pole breaker	4X
Main lug space	2X
Total	18X
Total box height	37 in.
Box width	28 in.
Box depth	9½ in.

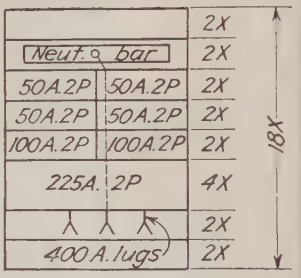


Fig. 166.

GENERAL WIRING MATERIALS AND DEVICES

99. Insulators of various types are employed for interior-wiring work where the conductors are not installed in raceways. The more common types may be classified as knobs, cleats, tubes, crane insulators, and rack insulators. The following sections and illustrations give data on many standard types. Insulators for outdoor and underground installations are discussed in Div. 8.

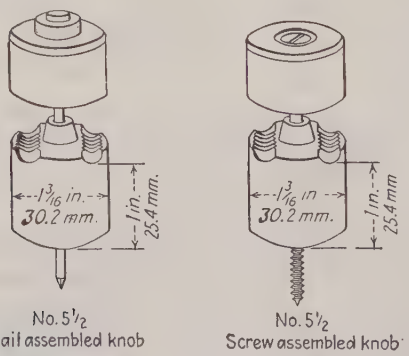
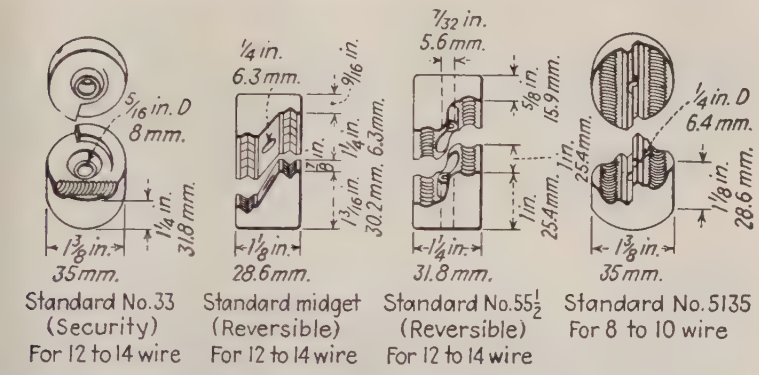


Fig. 167.—Assembled wiring knobs for No. 12 to No. 14 wire. (*The R. Thomas & Sons Co.*)

Split knobs are shown in Figs. 167 and 168. Those of Fig. 167 are factory assembled with a supporting nail or screw. Various standard types of solid knob insulators are shown in Fig. 169. Standard types of rack insulators are shown in Fig. 170. Standard wire cleats are shown in Figs. 171 and 172. Crane insulators are shown in Fig. 173. All these insulators are made of porcelain.

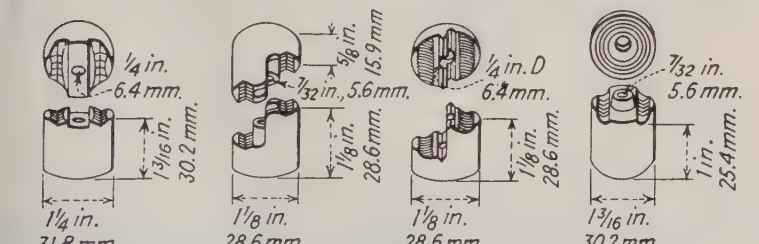


Standard No. 33 (Security) For 12 to 14 wire

Standard midget (Reversible) For 12 to 14 wire

Standard No. 55½ (Reversible) For 12 to 14 wire

Standard No. 5135 For 8 to 10 wire

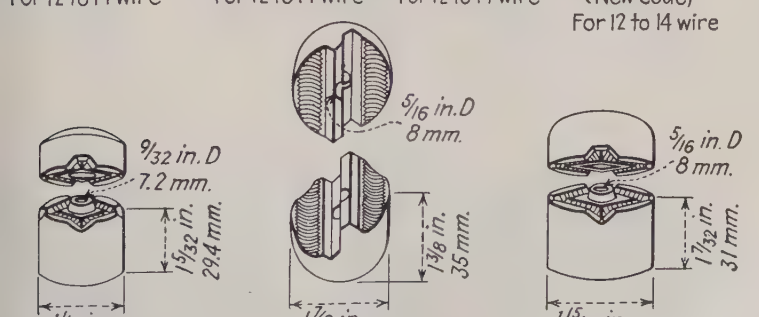


Standard Detroit For 12 to 14 wire

Standard No. 101 For 12 to 14 wire

Standard No. 5517 For 12 to 14 wire

Standard No. 5½ (New code) For 12 to 14 wire



Standard No. 9419 For 10 to 12 wire

Standard No. 5147 For 4 to 6 wire

Standard No. 9420 For 4 to 6 wire

FIG. 168.—Split knobs. (*The R. Thomas & Sons Co.*)

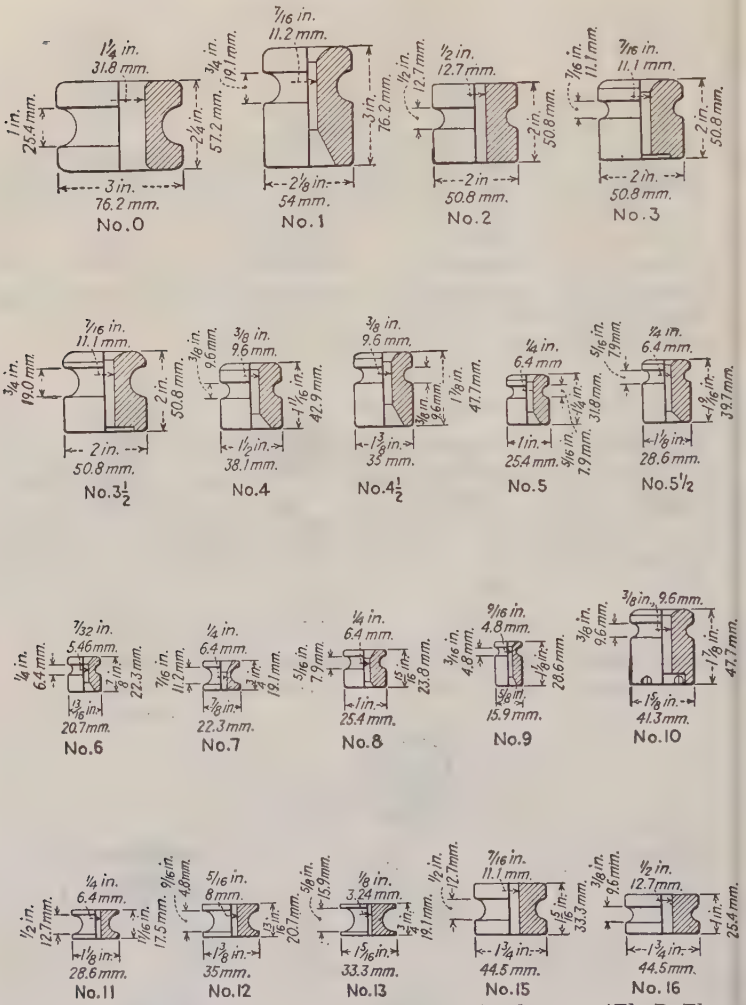


FIG. 169.—Various standard types of solid knob insulators. (*The R. Thomas & Sons Co.*)

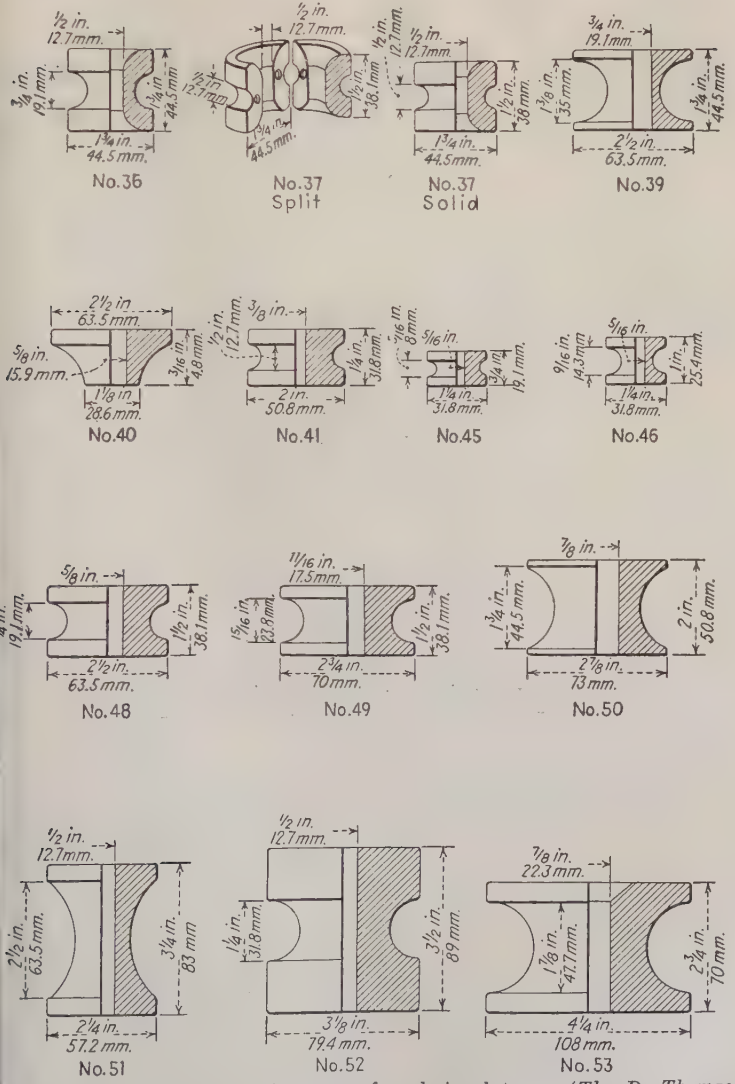
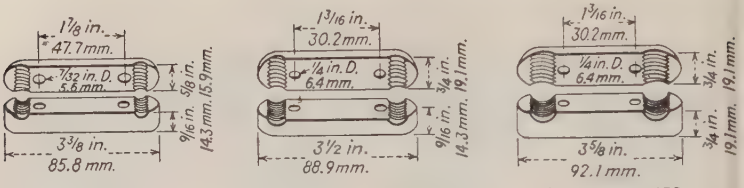


FIG. 170.—Various standard types of rack insulators. (*The R. Thomas & Sons Co.*)



	Size of Wire
Standard No. 334	No. 12 to No. 14
Standard No. 335	No. 8 to No. 10
Standard No. 350	No. 2 to No. 6

Fig. 171.—Two-wire cleats. Three-wire cleats can be obtained in the designs shown here. (*The R. Thomas & Sons Co.*)

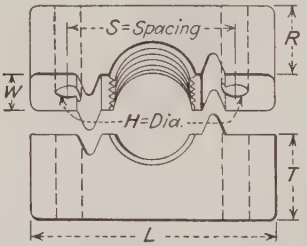


Fig. 172.—Single-wire cleats, B. & D. style, No. 110 to 129. (*The R. Thomas & Sons Co.*)

99A. Wire Table for B. & D. Single Wire Cleats

Size of wire received, B. & S. gage	Numbers		
	Light cap and light base	Light cap and heavy base	Heavy cap and heavy base
No. 14 to No. 6	110	115	120
No. 6 to No. 2	111	116	121
No. 2 to No. 1/0	112	117	122
No. 1/0 to 3/0	113	118	123
No. 3/0 to 200,000 cir. mils	114	119	124
200,000 to 500,000 cir. mils	...	...	126
500,000 to 1,000,000 cir. mils	...	...	127
800,000 to 1,250,000 cir. mils	...	...	128
1,000,000 to 2,000,000 cir. mils	...	...	129
No. 10 Duplex parallel conduit cable, ⅝ × ⅞ in. (16 × 22 mm.)	...	...	125

99B. Table of Dimensions for B. & D. Single-wire Cleats

Numbers	*L*		*S*		*W*		*H*		*R*		*T*	
	In.	Mm.	In.	Mm.	In.	Mm.	In.	Mm.	In.	Mm.	In.	Mm.
Light Cap and Light Base												
110	1⅞	48	1⅛	29	⅞	22	¼	6	5/8	16	5/8	16
111	2¼	57	1⅜	35	1	25	5/16	8	¾	19	¾	19
112	2⅝	67	1 11/16	43	1⅛	29	5/16	8	⅞	22	⅞	22
113	3	76	1 15/16	49	1¼	32	⅜	10	1	25	1	25
114	3⅜	86	2¼	57	1⅜	35	⅜	10	1⅛	29	1⅛	29
Light Cap and Heavy Base												
115	1⅞	48	1⅛	29	⅞	22	¼	6	5/8	16	1⅛	29
116	2¼	57	1⅜	35	1	25	5/16	8	¾	19	1 3/16	30
117	2⅝	67	1 11/16	43	1⅛	29	5/16	8	⅞	22	1¼	32
118	3	76	1 15/16	49	1¼	32	⅜	10	1	25	1 5/16	33
119	3⅜	86	2¼	57	1⅜	35	⅜	10	1⅛	29	1⅜	35
Heavy Cap and Heavy Base												
120	1⅞	48	1⅛	29	⅞	22	¼	6	1⅛	29	1⅛	29
121	2¼	57	1⅜	35	1	25	5/16	8	1 3/16	30	1 3/16	30
122	2⅝	67	1 11/16	43	1⅛	29	5/16	8	1¼	32	1¼	32
123	3	76	1 15/16	49	1¼	32	⅜	10	1 5/16	33	1 5/16	33
124	3⅜	86	2¼	57	1⅜	35	⅜	10	1⅜	35	1⅜	35
125	3⅜	86	2¼	57	1⅜	35	⅜	10	1⅜	35	1⅜	35
126	4¼	108	2 15/16	75	1⅝	41	7/16	11	1 9/16	40	1 9/16	40
127	4¾	121	3¼	83	1 13/16	46	9/16	14	1¾	44	1¾	44
128	5⅜	137	3 1/16	97	2	51	9/16	14	2	51	2	51
129	6	152	4⅜	111	2¼	57	9/16	14	2¼	57	2¼	57

100. Use of Screws or Nails with Split Knobs.—Nails hold better than screws in certain woods. The breaking of knobs at the time of putting them up with screws is not the only source of trouble, for the binding tension applied often acts to crack the knob a considerable time after it has been put in place. It is an objectionable practice of many wiremen in putting up knobs with screws to drive the screws in nearly all the way with a hammer, giving them only a couple of turns with a screw driver to tighten them. The principal argument in favor of the use of the nail is the great saving of the wiremen's time that results as compared with that required for putting in screws. The insulating value of either construction is practically the same.

101. Insulated racks are often convenient for supporting cables in open wiring installations. They consist (Fig. 174) of porcelain insulators mounted in an iron base and clamped together with an iron top for d-c work and a brass top for a-c work. They are made in assemblies for one, two, three, and four cables and can be supplied with insulator openings of inside diameters ranging from 3/16 to 3 in. The diameters vary by 1/16 in. from 3/16- to 5/8-in. sizes and by 1/8 in. from 5/8- to 3-in. sizes.

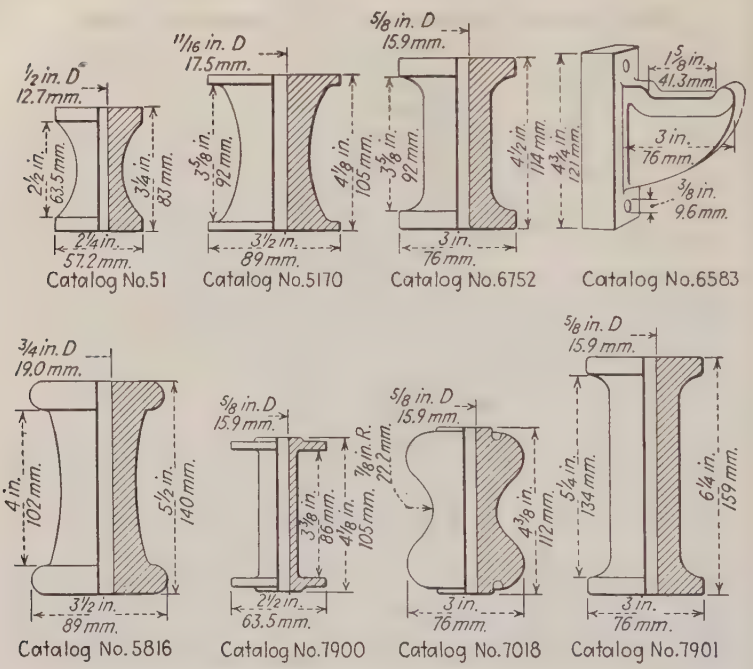
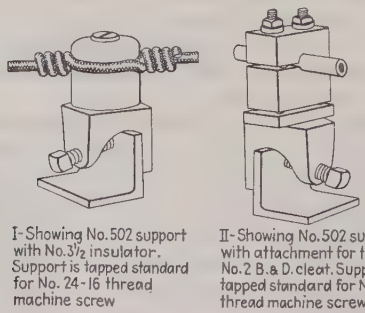


FIG. 173.—Crane insulators. (*The R. Thomas & Sons Co.*)

FIG. 174.—Insulated cable rack. (*Westinghouse Electric & Manufacturing Co.*)



I- Showing No. 502 support with No. 3½ insulator. Support is tapped standard for No. 24-16 thread machine screw

II- Showing No. 502 support with attachment for type A No. 2 B. & D. cleat. Support is tapped standard for No. 24-16 thread machine screw

FIG. 175.—Universal insulator supports. (*Steel City Electric Co.*)

102. Universal insulator supports (Fig. 175) are malleable-iron clamps fitted with cup-pointed, core-hardened, steel setscrews for securing porcelain and glass insulators to exposed steel framework.

103. Porcelain tubes are made in three types: standard solid tube, split tube, and floor tube. The standard lengths, as indicated by the *L* dimension in Fig. 176, are ½, 1, 1½, 2, 2½, 3, 4, 5, 6, 8, 10, 12, 14, 16, 18, 20, 22, and 24 in. The diameters are given in Sec. **104.**

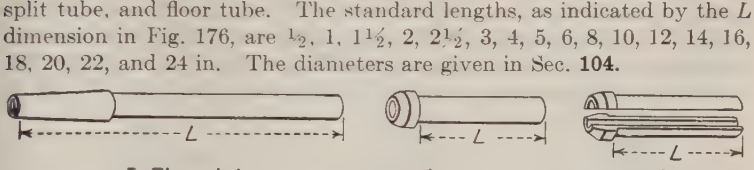


FIG. 176.—Porcelain insulating tubes.

104. Tube Diameters

Diameters	Tube size (see Sec. 103)													
	5/16	3/8	1/2	5/8	3/4	1	1¼	1½	1¾	2	2¼	2½	2¾	3
Outside diam., in	9/16	11/16	13/16	15/16	1 3/16	1 7/16	1 11/16	2 3/16	2 9/16	2 15/16	3 5/16	3 11/16	4¼	4½
Outside diam., mm	14.3	17.5	20.6	23.8	30.2	36.5	46.1	55.6	65.1	74.6	84.1	93.7	108	114
Inside diam., in	5/16	3/8	1/2	5/8	3/4	1	1¼	1½	1¾	2	2¼	2½	2¾	3
Inside diam., mm	7.9	9.5	12.7	15.9	19.1	25.4	31.7	38.1	44.5	50.8	57.1	63.5	69.8	76.2

105. Receptacles and caps or plugs are wiring devices for the purpose of providing a convenient and safe means of connecting portable appliances or equipment to an electric circuit.

The receptacle consists of stationary contacts mounted in an insulating enclosure and with openings so that the blades of attachment caps or plugs may be inserted so as to make contact with the stationary contacts.

The cap or plug consists of projecting blades mounted in an insulating enclosure with provision for attachment to a portable cord.

Receptacles may be roughly classified as follows:

A. According to method of installation.
  1. For flush mounting.
     a. Standard line.
     b. Interchangeable line.
     c. Combination line.
  2. For surface mounting for exposed wiring on insulators.
  3. For mounting in special enclosures.

B. According to number and arrangement of blades.
  1. Two pole, parallel blades.
  2. Two pole, tandem blades.
  3. Two pole, blades polarized.
  4. Three pole.
  5. Four pole.

Receptacles and caps or plugs are made in such a variety of designs that only some very general remarks can be given here. The flush types are designed for mounting inside standard sectionalized switch boxes, outlet boxes, or conduit fittings. The assembly is then covered with a special outlet box or conduit-fitting cover or with a standard wiring-device flush plate. Flush receptacles are made in three types as listed above. The standard line (Fig. 177) is made with more generous proportions than the other two and is the most rugged of the three

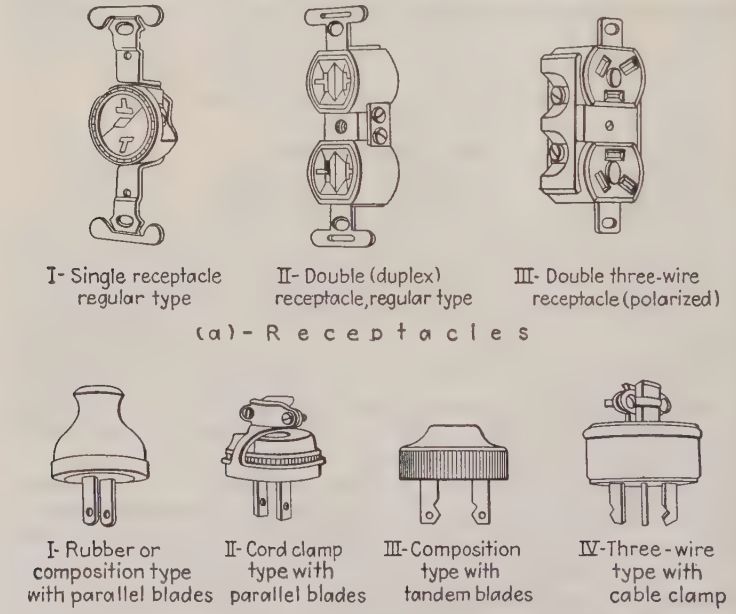


Fig. 177.—Standard line of receptacles and plugs. (*Pass & Seymour, Inc.*)

types. It should be used for heavy-duty installations. The over-all dimensions of the body range from 1 to $3\frac{1}{32}$ in. in depth, $1\frac{5}{16}$ to $1\frac{3}{4}$ in. in width, and from $1\frac{3}{8}$ to $2\frac{1}{2}$ in. in length. Most of these receptacles are supplied with supporting straps with two sets of supporting screw holes, spaced from center to center $3\frac{9}{32}$ and $2\frac{3}{8}$ or $2\frac{13}{16}$ in., respectively. They are available in double-, three-, and four-pole types up to 20-amp. capacity at 250 volts. The regular two-pole receptacles are so constructed that they will accommodate blades arranged in parallel or tandem (Fig. 177, *a*I, *a*II, and *b*I, *b*II, and *b*III). Receptacles of the polarized type (Fig. 177, *a*III) will accommodate only plugs with special blade arrangement (Fig. 177, *b*IV). Such receptacles and plugs are necessary where it would be possible to connect appliances to different supply

ystems or for d-c systems where a definite polarity must be applied to he appliance. Regular two-pole receptacles of 15-amp. capacity at 25 volts or 10-amp. capacity at 250 volts are made in single- and twin-utlet types (Fig. 177, *a*I and *a*II), either of which occupies one gang pace in the outlet box.

The interchangeable line of receptacles (Fig. 178) is constructed in a nuch more compact manner with less generous proportions. As many s three of these receptacles may be included in one gang space in the

Fig. 178.—Interchangeable line of receptacles and plugs. (*Pass & Seymour, Inc.*)

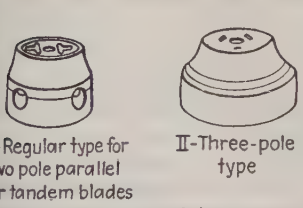


Fig. 179.—Porcelain receptacles of the surface type. (*Pass & Seymour, Inc.*)

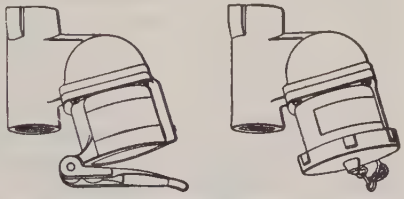


Fig. 180.—Heavy-duty industrial receptacles. (*Crouse Hinds Co.*)

utlet box. They should not be used for heavy-duty installations. Only wo-pole receptacles are made and are rated at 15 amp. at 125 volts nd 10 amp. at 250 volts. Different combinations of switches, recep-acles, and pilot lights, up to three units, may be assembled on a single upporting strap yoke and mounted in a single gang space (see Sec **30**).

The combination line of receptacles is similar to the interchangeable ne in general construction and service for which they are suited (refer o Sec. **30** for additional information).

Receptacles of the surface type are made in several varieties for xposed wiring on insulators. Two common types are shown in Fig. 179.

Heavy-duty receptacles (Fig. 180) mounted integrally with special onduit fittings are used for industrial purposes requiring high current apacity or especially hard duty. They are available in nonwatertight nd watertight assemblies.

Weatherproof assemblies for general-purpose receptacles are made for nstallations requiring protection against exposure to weather.

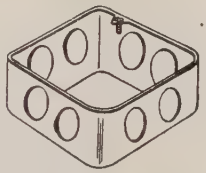
106. A box must be installed at each outlet, switch, or junction poin for all wiring installations except for exposed wiring on insulators or o cable. An outlet is any point in a wiring system where current is take for supplying fixtures, lamps, heaters, or any other current-consumin equipment. The boxes must be constructed of metal except for ope wiring on insulators, concealed knob and tube work, nonmetallic-sheathe cable, or nonmetallic waterproof wiring. In these installations boxe made of insulating material may be used (see Div. 8). Boxes used i interior wiring work may be classified as outlet, utility, sectional switch and floor boxes. Those classed as outlet boxes are primarily intended fo concealed wiring installations where the box will not be exposed to view Utility boxes are designed principally for exposed wiring. Condui fittings (see Div. 8) are used at the outlets for the great majority o exposed-conduit wiring installations. The regular outlet boxes may b used for exposed work, but they do not produce an installation of ver good appearance. Sectionalized switch boxes are used in conceale wiring when not embedded in masonry structure. Floor boxes are use for making outlets in floors from conduit wiring systems. Boxes ar made of No. 10 to 14 gage sheet steel. The surfaces may be galvanize or black enameled. Galvanized boxes will resist corrosion and provid better assurance of preserving the electrical conductivity of the racewa system. Black enamel boxes give a better appearance for exposed work The different types of boxes are illustrated in Sec. **111** with the dimension in which they are most commonly available. The dimensions of boxe vary somewhat with different manufacturers.

107. Outlet boxes are made in round, square, octagonal, and oblon shapes. Round boxes should never be used where a conduit must ente the box through the side, as it is difficult to make a good connection wit a lock nut or bushing on a rounded surface.

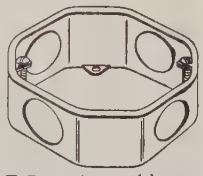
The **round** and **octagonal** boxes are used for ceiling outlets in all type of concealed wiring installed in buildings of all types of construction The octagonal boxes are also used for wall-bracket lighting outlets. Bot round and octagonal boxes are made with various combinations of knock outs in sides and bottom and with built-in clamps for armored cable o nonmetallic-sheathed cable. They may be obtained with built-in $\frac{3}{8}$ or $\frac{1}{2}$-in. fixture studs or with holes for mounting a separate fixture stud Various types of covers are available for these boxes as shown in Sec. **112** Some are of the flat type, while others have the central portion of th cover raised so that additional interior space is made available in the box Octagonal boxes constructed especially for concrete work have th bottom or back plate, as it is called, detachable from the sides. The back plate and sides are provided with conduit knockouts. The back plat may be provided with $\frac{3}{8}$- or $\frac{1}{2}$-in. built-in fixture studs or with hole for mounting a separate fixture stud.

Square and **oblong** boxes are used principally for side-wall outlets i conduit wiring when embedded in masonry or installed in brick or til

walls. Sometimes they also are used with conduit wiring in other types of building construction. The square boxes are used sometimes for ceiling outlets. The oblong boxes frequently are called gang boxes and are used where more internal space is required than is provided by the square boxes. The term **gang** refers to the number of standard-line wiring devices which the box will accommodate. A three-gang box will accommodate three standard wiring devices mounted side by side. They are made with various combinations of knockouts in sides and bottom. The square boxes may be provided with $\frac{3}{8}$- or $\frac{1}{2}$-in. built-in fixture studs or with holes for mounting separate fixture studs. Various types of covers are available for the square boxes as shown in Sec. **112.** Covers are available with openings and supporting lugs for the accommodation of flush wiring devices. The opening is then covered with a standard flush plate. The portion of the box cover around the central opening is raised so that the box is set back a slight amount in the wall and the cover brings the surface of the wiring device flush with the wall surface. The box and the box cover are plastered over a sufficient amount so that the remaining opening will be completely covered with the flush plate. Covers are available with the central portion raised different amounts in order to accommodate different thicknesses of plaster. The covers for the oblong boxes are always of the type just described. When the square boxes are used in exposed wiring, a flush plate would not give a neat appearance, so that an outlet box cover is used, which covers the entire opening of the box. Openings in the cover accommodate switch handles or receptacles.



I- For square box



II-For octagonal box

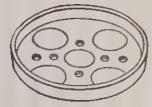
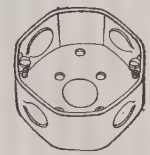
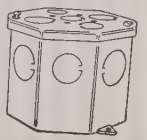
FIG. 181.—Outlet-box extension rings.

108. Utility boxes are designed for use in exposed-conduit wiring installations in order to provide a neat-appearing job. They are provided with knockouts in bottom and sides. Data on covers are given in Sec. **112.**

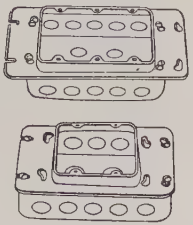
109. Sectional switch boxes are employed in concealed wiring installations which are not embedded in masonry. They are constructed with removable sides so that any number of boxes may be ganged side by side in order to provide compactly for several wiring devices at one location. No covers are required since they are designed to accommodate the standard flush wiring devices with standard flush plates. They are made in types with conduit knockouts and with clamps for armored cable, nonmetallic-sheathed cable, and loom. Most boxes are 3 in. long and 2 in. wide.

110. Extension rings (Fig. 181) are available for octagonal and square boxes in order to increase the depth of the box. The standard depths in which they are available for the different boxes are given in Sec. **112.**

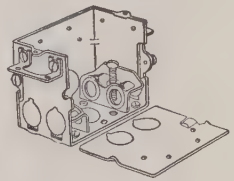
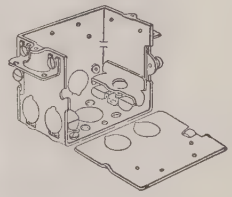
111. Data on Wiring Boxes

Shape of box	Illustration	Width and length, in.	Depth, in.	Depth of extension rings, in.
		Outlet Boxes		
Round		3¼ diam.	¾ 1½	None regularly available
		3½ diam.	½	
		4 diam.	½ ¾	
Octagonal		3¼	1½	1½
		3½	1½	1½
		4	1½ 2⅛	1½ and 2⅛ 1½ and 2¼
Octagonal concrete boxes		Backplate, 4 or 4 7/16 Body, 4	1½ 2 2½ 3 3½ 4 5 6	None regularly available

Data on Wiring Boxes (*Continued*)

Shape of box	Illustration	Width and length, in.	Depth, in.	Depth of extension rings, in.
Square		4×4	$1\frac{1}{4}$ $1\frac{1}{2}$ $2\frac{1}{8}$	$1\frac{1}{2}$ and $2\frac{1}{8}$
		$4\frac{11}{16} \times 4\frac{11}{16}$	$1\frac{1}{2}$ $2\frac{1}{8}$	$1\frac{1}{2}$ and $2\frac{1}{8}$
Oblong gang boxes		$4\frac{1}{4}$ or $4\frac{1}{2}$ $\times$ { $6\frac{13}{16}$ (two gang); $8\frac{5}{8}$ (three gang); $10\frac{1}{2}$ (four gang); $12\frac{1}{4}$ (five gang); $14\frac{1}{16}$ (six gang); $15\frac{15}{16}$ (seven gang); $17\frac{3}{8}$ (eight gang); $19\frac{1}{2}$ (nine gang)	Generally $1\frac{3}{4}$ or $1\frac{11}{16}$. Available from some manufacturers in $1\frac{1}{2}$ and $2\frac{1}{2}$	None regularly available
Utility Boxes				
Oblong		$4\frac{1}{8}$ or $4 \times 2\frac{1}{8}$	$1\frac{1}{2}$ $1\frac{7}{8}$ $2\frac{1}{8}$	None regularly available

Data on Wiring Boxes (*Continued*)

Shape of box	Illustration	Width and length, in.	Depth, in.	Depth of extension rings, in.
		Sectional Boxes		
Oblong		3 × 2	1½ 2 2½ 3 } For use with metallic armored cable	None regularly available
		3 × 2	2 2¼ 2 } For use with nonmetallic armored cable	None regularly available

Data on Wiring Boxes (*Continued*)

Shape of box	Illustration	Width and length, in.	Depth, in.	Depth of extension rings, in.
		3 × 2	1½ 2 2½ 2¾ 3½ } For use with rigid conduit	None regularly available
		3 × 2	2¼ For use with loom	None regularly available

112. Box Covers

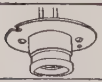
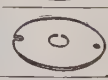
Illustration	Description
For 3¼-in. Round and Octagonal Boxes	
	Raised, closed; ⅜ in. deep
	Flat, closed
	Raised, with 1²¹⁄₃₂-in. keyed opening for Federal sign receptacle. ⅜ in. deep,
	Flat, with 1⁹⁄₁₆-in. opening and screw holes on 1¾ in. centers for Benjamin sign receptacle
	Flat, with ½-in. knockout in center
	Raised, with ½-in. knockout in center; ⅜ in. deep
	Raised, with 1½-in. opening for sign receptacles notched for protruding lug on porcelain; ⅜ in. deep
	Raised, with 1½ in. diameter opening and bent tongue to fit notches in new standard sign receptacles; ⅜ in. deep
	Raised, with ²⁷⁄₆₄-in. metal eyelet for drop cord; ⅜ in. deep
	Flat, with slots for surface devices; opening 1¹⁵⁄₁₆ in., screw centers 1⁵⁄₁₆ in. to 1¹³⁄₁₆ in.
	Cover with pigtail receptacle
	Cover with terminal receptacle
For 3½-in. Round and Octagonal Boxes	
	Flat, closed

Illustration	Description
	Flat with ½-in. knockout in center
	Flat with slots for surface devices
	Raised, closed; ⅝ in. deep
	Raised with ½-in. knockout in center, ⅝ in. deep
	Raised with ⅜-in. eyelet; ⅝ in. deep
	Raised with 1½-in. grooved opening; ⅝ in. deep
	Raised with plain 1½-in. opening; ⅝ in. deep
For 4-in. Round and Octagonal Boxes	
	Raised, closed, ⅝ in. deep
	Flat, closed
	Flat, with ½-in. knockout in center
	Raised, with ½-in. knockout in center; ⅝ in. deep
	Raised, with 2¾-in. opening; ⅝ in. deep
	Raised, ⅝ in. high, for one flush device; also suitable for bracket outlet
	Raised, ⅝ in. high with 1½ in. diameter opening for sign receptacles notched for protruding lug on porcelain

Box Covers (*Continued*)

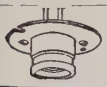
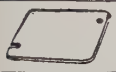
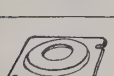
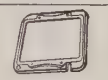
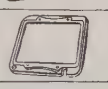
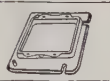
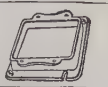
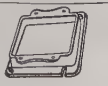
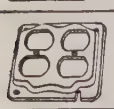
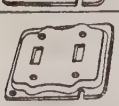
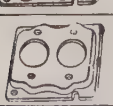
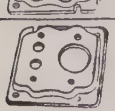
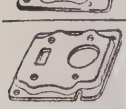
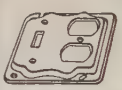
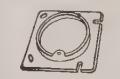
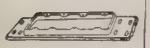
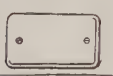
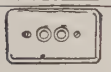
Illustration	Description
	Raised $\frac{5}{8}$ in., with $1\frac{1}{2}$-in. diameter opening and bent tongue to fit notches in new standard sign receptacles
	Raised $\frac{5}{8}$ in., with $\frac{27}{64}$-in. metal eyelet for drop cord
	Raised $\frac{5}{8}$ in., $2\frac{3}{4}$-in. opening, $1\frac{15}{16}$ in. deep lugs tapped 8-32 on $2\frac{3}{4}$-in. centers
	Flat, with slots for surface devices; opening $1\frac{15}{16}$ in., screw centers $1\frac{5}{16}$ to $1\frac{13}{16}$ in.; two $\frac{7}{8}$-in. × 6-32 screws
	Cover with pigtail receptacle
	Cover with terminal receptacle
For 4-in. Square Boxes	
	Raised, closed, $\frac{5}{8}$ in. deep
	Flat closed cover
	Flat with $\frac{1}{2}$-in. knockout in center
	Raised, $\frac{5}{8}$ in. deep with $\frac{1}{2}$-in. knockout in center
	Raised with $2\frac{3}{4}$-in. opening; $\frac{5}{8}$ in. deep
	Raised with $1\frac{1}{2}$-in. opening for sign receptacles, notched for protruding lug on porcelain; $\frac{5}{8}$ in. deep
	Raised with $1\frac{1}{2}$-in. opening and bent tongue to fit notches in new standard sign receptacle; $\frac{5}{8}$ in. deep

Illustration	Description
	Raised with $\frac{27}{64}$-in. metal eyelet for drop cord; $\frac{5}{8}$ in. deep
	Raised with $2\frac{3}{4}$-in. opening, $\frac{5}{8}$ in. deep; lugs tapped 8-32 on $2\frac{3}{4}$-in. centers
	Flat, with slots for surface devices, opening $1\frac{15}{16}$ in., screw centers $1\frac{5}{16}$ and $1\frac{13}{16}$ in.
For 4-in. Square Boxes to Accommodate Flush Wiring Devices with Flush Plate Covers	
	Raised $\frac{1}{4}$ in. for one-gang plate
	Raised $\frac{1}{4}$ in. for two-gang plate
	Raised $\frac{1}{2}$ in. for one-gang plate
	Raised $\frac{1}{2}$ in. for two-gang plate
	Raised $\frac{3}{4}$-in. for one-gang plate
	Raised $\frac{3}{4}$-in. for two-gang plate
	Raised 1 in. for one-gang plate
	Raised 1 in. for two-gang plate
	Raised $1\frac{1}{4}$ in. for one-gang plate
	Raised $1\frac{1}{4}$ in. for two-gang plate

Box Covers (*Continued*)

Illustration	Description
For 4-in. Square Boxes for Accommodating Flush Wiring Devices in Exposed Wiring	
	Raised ½ in.; for one push-button switch
	Raised ½ in.; for one square-handle toggle switch
	Raised ½ in.; for one single flush receptacle
	Raised ½ in.; for one duplex receptacle
	Raised ½ in.; for two duplex receptacles
	Raised ½ in.; for two push-button switches
	Raised ½ in.; for two square-handle toggle switches
	Raised ½ in.; for two single flush receptacles
	Raised ½ in.; for one push-button switch and one single flush receptacle
	Raised ½ in.; for one square-handle toggle switch and one single flush receptacle
	Raised ½ in.; for one push-button switch and one duplex receptacle
	Raised ½ in.; for one square-handle toggle switch and one duplex receptacle
For $4^{11}/_{16}$-in. Square Boxes	
	Raised, closed; ⅝ in. deep
	Flat, closed
	Flat with ½-in. knockout in center
	Raised with ½-in. knockout in center; ⅝ in. deep
	Raised, with $2^{3}/_{4}$-in. opening; ⅝ in. deep
	Raised, with $2^{7}/_{64}$-in. metal eyelet for drop cord; ⅝ in. deep
	Raised, with $2^{3}/_{4}$-in. opening, ⅝-in. deep; lugs tapped 8-32 on $2^{3}/_{4}$-in. centers
For $4^{11}/_{16}$-in. Square Boxes for Accommodating Flush Wiring Devices and Flush Plate Covers	
	Raised ¾ in. for one-gang plate
	Raised 1 in. for one-gang plate
	Raised $1^{1}/_{4}$ in. for one-gang plate
	Raised ¾ in. for two-gang plate

Box Covers (*Continued*)

Illustration	Description	Illustration	Description
For Oblong Gang Boxes for Accommodating Flush Wiring Devices and Flush Plate Covers			For standard duplex receptacle
	Available for two-, three-, four-, five-, six-, seven-, eight-, and nine-gang flush plates		For standard square-handle toggle switch
For Utility Boxes			For single T-slot and Edison-base receptacle
	Blank		Cover with knockouts for interchangeable devices
	For single push-button switch		

113. Flush plates are covers which are used with flush wiring devices in concealed wiring installations in order to produce a neat covering of the outlet. They are supported by screws turning into tapped holes in mounting ears or straps on sectional boxes or on covers for square or oblong boxes as described in Sec. **112.** Holes in the plates accommodate the handles of flush switches or plugs for flush receptacles. They are made in single-, two-, and three-gang sizes with various types and combinations of openings to meet almost any combination of flush wiring devices. Flush plates made of bakelite, brass, enameled metal, or stainless steel may be obtained. The standard finish for brass plates is brush brass. Plates may be obtained with almost any special finish in order to meet the requirements of any interior. Some of these special finishes are listed below:

FLUSH PLATE FINISHES

Aluminum (spray).
Barff, Bauer lacquer.
Black lacquer.
Brass, sand blast, antique.
sand blast, brush.
Flemish.
lemon.
oxidixed.
polished.
Bronze antique.
brush.
Japanese (dark).
Bronze, polished.
statuary (light).
Brown lacquer (imitation bakelite).
Cadmium, brushed.
polished.
Chromium, dull.
polished.
Copper, antique
brush.
mottled.
oxidized.
polished.
Gilt, rich.
Gun metal
Ivory enamel.
Nickel, dull.
polished.
Silver, butler's (brushed).
oxidized.
polished.
satin.
Verde-antique lacquer.
White enamel.

Flush plates are made for the standard, interchangeable, and combination line of wiring devices. Typical plates are shown in Figs. 182 and 183.

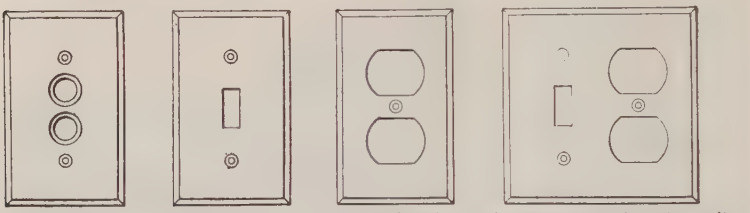


FIG. 182.—Flush plates for standard-line wiring devices.

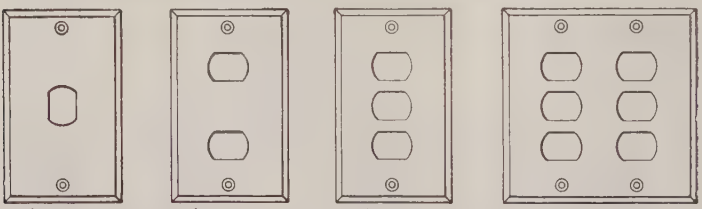
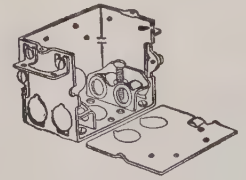
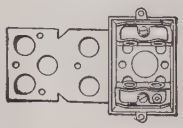
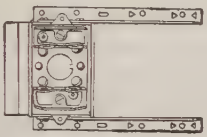
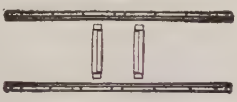
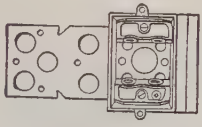
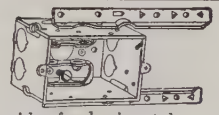
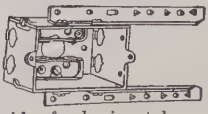
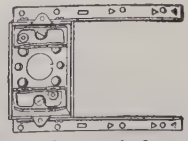


FIG. 183.—Flush plates for interchangeable-line wiring devices.

114. Types of Mounting Features for Sectional Boxes

Name	Illustration	Description
Standard mounting ears		Box equipped with two ears, one secured to each end of box with two 8-32 large fillister-head screws. Ears adjustable and reversible. Set of extra holes (not tapped) in each side for changing position of ears to sides if desired (8-32 tap required)
Rectangular mounting bracket without lath support		For plaster or wallboard jobs, with holes for gripping plaster and with aligning-cleat prongs and four nail holes. Bracket is perfectly flat so it does not interfere with wallboard. Bracket is welded to box

Types of Mounting Features for Sectional Boxes (*Continued*)

Name	Illustration	Description
Extended mounting ears	 Ears on ends for vertical mounting in plaster with lath support.	For mounting in plaster or baseboard. Each ear fastened to box with two 8-32 fillister-head screws. Can be located on sides or ends. Tapped mounting holes supplied regularly only on ends. Aligning cleat prongs and adequate nail holes for rigid fastening
Box supports and lath holders		For mounting in plaster walls. Supports available in lengths of 16½, 18½, 20½, 22½, 24½, and 26½ in.
Rectangular mounting bracket with lath support		Same as item 2 with lath supports welded to box for wood-lath or wallboard jobs. Back lip of support projects beyond front lip providing adequate support behind wall board and still retaining channel for supporting end of wood lath front and back
Extended mounting ears	 Ears on sides for horizontal mounting in baseboards.  Ears on sides for horizontal mounting in plaster.  Ears on ends for vertical mounting in plaster without lath support.	For mounting in plaster or baseboard. Each ear fastened to box with two 8-32 fillister-head screws. Can be located on sides or ends. Tapped mounting holes supplied regularly only on ends. Aligning cleat prongs and adequate nail holes for rigid fastening

115. Depth of Outlet Boxes.—The National Electrical Code specifies that outlet boxes must have an internal depth of at least 1½ in. for concealed work except that, where the installation of such a box is impracticable, a box of not less than ½ in. internal depth may be used. Outlet boxes with conduits entering the side should be 2⅛ in. deep for installation in lath and plaster. Boxes 1½ in. deep will generally be satisfactory for brickwork. The shallow boxes of ½- or ¾-in. depth are sometimes used on terra-cotta ceilings with the box set on the surface of the tile and embedded in the plaster. The conduits are brought into the back of the box. Refer to Div. 9, Sec. **237.**

116. Metal straps for supporting outlet boxes can be obtained in various types with or without attached fixture studs. Several representative types made by the National Electric Products Corp. are described below.

A

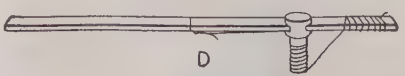
For shallow boxes in new work or for holding boxes to concrete forms. With boxes of a depth of ½ in., where bar is nailed to joists or studding, edge of box will be flush with ordinary plaster. Will fit any box having ½-in. knockout. Made in 18- and 24-in. lengths.

B

For boxes 1½ in. deep without switch covers or plaster rings; offset brings box edge flush with plaster. Will fit any box having ½-in. knockout. Length of bar 19½ in. Offset 1$\frac{1}{16}$ in. deep.

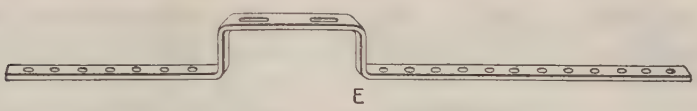
C

For boxes 1½ in. deep with switch covers or plaster rings; offset brings covers ⅝-in. high, flush with plaster. Will fit any box having ½-in. knockout. Length of bar 19½ in. Offset 1$\frac{11}{16}$ in. deep.



D

For mounting shallow boxes or plates in buildings already plastered. Make a small hole about 1½ in. in diameter; push bar all the way into hole, long end first as shown in cut; hold stud in one hand and pull wire with the other until bar is centered across hole. Will fit any box having ½-in. knockout. Length of bar 12 in.



For boxes $1\frac{1}{2}$-in. deep with covers and integral studs, or without studs. Offset has slots for stove bolts to hold box and is right depth to bring $\frac{5}{8}$-in. covers flush with plaster. Length of bar 21 in. Offset $1\frac{11}{16}$ in. deep.

117. A special type of switch-box support made by the General Electric Co. is described below.

1. The Hold-it switch-box support consists of a pair as illustrated in Fig. 184.

Fig. 184.

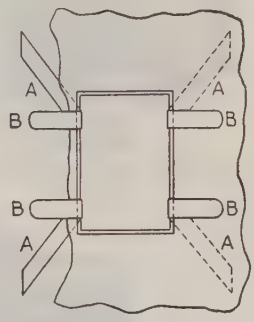


Fig. 185.

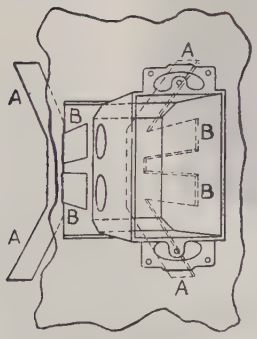


Fig. 186.

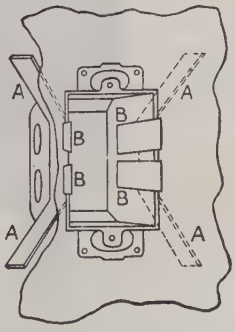


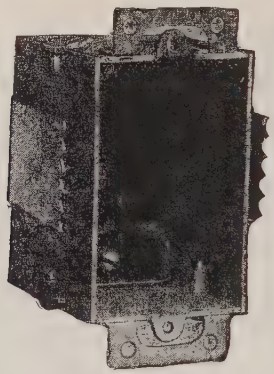
Fig. 187.

2. Cut opening to fit box snugly. Bend the two legs *AA* as shown in Fig. 185. Insert in opening one Hold-it on each side bending fingers *BB* back against the wall surface on outside.

3. Insert the box in the usual manner and press ears of box firmly against the wall (Fig. 186).

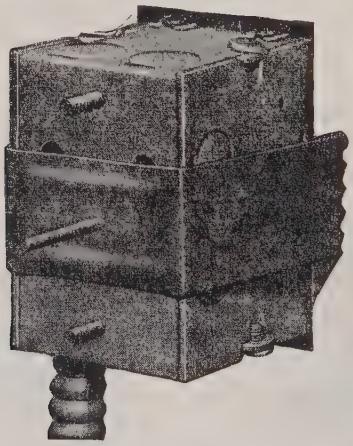
4. Bend fingers *BB* over edge into inside of box securely anchoring box in place (Fig. 187).

118. Wallboard Hanger (General Electric Co.).—Instructions for supporting a switch box with a special wallboard hanger are given below and illustrated in Fig. 188.



I. Assembled with switch box

II. Wallboard hanger



III. Rear view, installed

FIG. 188.—Wallboard switch hanger. (*General Electric Co.*)

For installing switch boxes in old work where plaster, wallboard, plasterboard, or similar construction is present:

1. Cut hole exact size of switch box.
2. Assemble switch box and hanger. Only partially tighten bolt.
3. Push assembly into wall hole until the sides of the hanger spring free on inside wall.

4. Tighten by screwing bolt on inside of box.

Inside and outside pressure against the wall give box a rigid installation.

119. Floor boxes (Fig. 189) are made in adjustable and nonadjustable types for providing outlets from concealed conduits embedded in floors. The adjustable ones allow the top to be adjusted in height and angle to suit the floor conditions. They may be obtained in single- and multiple-outlet units.

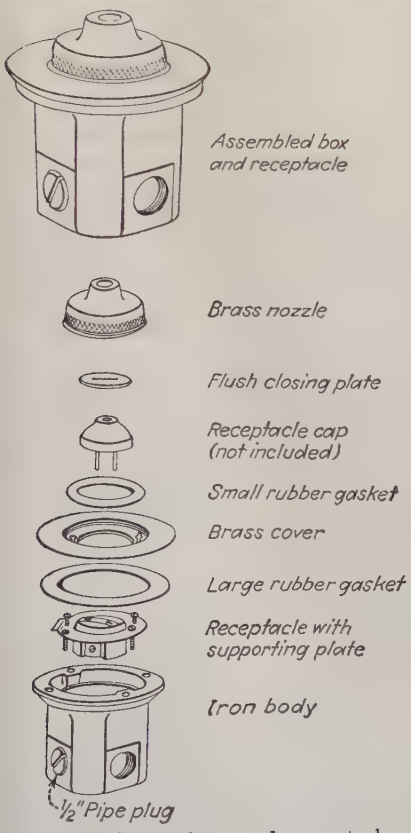


FIG. 189.—Floor box and receptacle. (*General Electric Co.*)

120. Door boxes (Fig. 190) are for the installation of door switches in the jamb of the door. They are made in different types in order to accommodate the different types of door switches.

121. Pull boxes are described in Div. 9.

122. Lamp holders consist of an assembly for supporting lamps, comprising the lamp socket, protective and insulating covering, and means for attachment to some form of support. The term socket is sometimes incorrectly used in place of lamp holder. Each lamp holder must have a lamp socket, but the socket is only

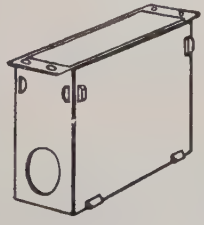


FIG. 190.—One type of door box.

the part of the lamp holder which engages with the base or terminal of the lamp. Lamp holders are made in a great variety of types in order to fulfill the requirements of all classes of installations and types of lamp bases.

123. Brass-shell-type interchangeable lamp holders are the old standard type. They consist of two fundamental parts, a body (Fig.

191, III) and a cap (Fig. 191, I) or base (Fig. 191, II). The two parts are held together by means of a fluted catch which allows them to be easily separated or assembled. Any cap or base may be used with any body.

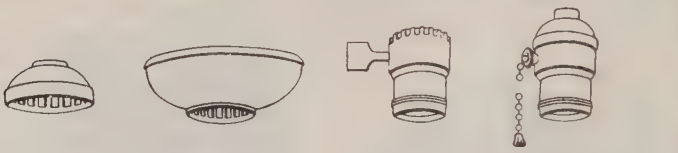


FIG. 191.—Fluted catch, interchangeable lamp holders. (*General Electric Co.*)

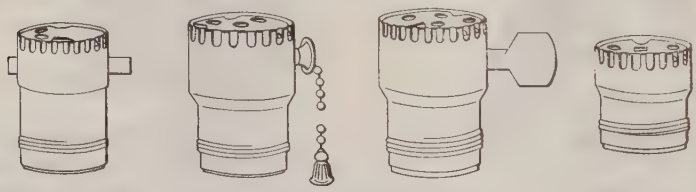


FIG. 192.—Types of fluted-catch lamp-holder bodies. (*Pass & Seymour, Inc.*)

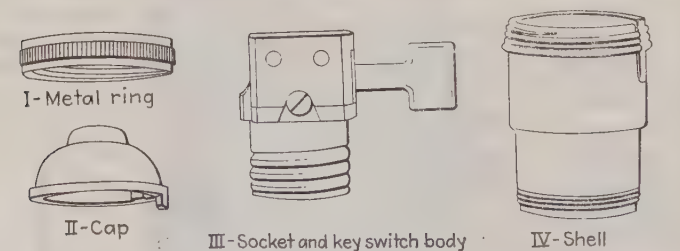


FIG. 193.—Threaded-catch interchangeable lamp holders. The threaded metal ring (I), knurled to provide a grip, holds the cap and shell together. The cap (II) cannot pull loose from the shell, and no amount of vibration will loosen the threaded ring when properly assembled. A lug in the cap fits in the shell slot, preventing rotation between cap and shell. After the cap has been fitted to the shell, the flange on the threaded ring fits over the flange on the cap, and the ring is securely threaded to the shell. (*General Electric Co.*)

The body consists of the socket mounted on a porcelain or composition support and encased in an outside brass shell. The socket is insulated from the shell by means of a fiber casing. When the porcelain or composition portion of the body simply forms a support and assembly for the socket and electric circuit connecting screws, it is known as a key-

less body. If the body contains a small switch for turning the lamp on or off, it may be of the key, pull-chain, or push type (Fig. 192). Caps are made with standard inside pipe thread for connection to $\frac{1}{8}$, $\frac{1}{4}$, $\frac{3}{8}$, or $\frac{1}{2}$-in. pipe or with $\frac{3}{8}$-in. male thread. Caps are also constructed with porcelain- or composition-bushed holes or with cord-clamp grip for pendant support on a drop cord. The cord holes are 0.406 in. in diameter, and the cord grips will accommodate cords from 0.375 to 0.5000 in. in diameter. Bases are available for mounting directly on outlet boxes and for exposed wiring either of the cleat-mounting or concealed-base type.

124. Threaded-catch interchangeable lamp holders (Fig. 193) are a newer development. They consist of a body fastened by means of a threaded ring to a cap or base. The bodies, caps, and bases may have outer brass shells or may be made of composition. The same types of bodies, caps, and bases are made as for the fluted-catch ones of Sec. **123.** The line is interchangeable in that any cap or base will fit any body.

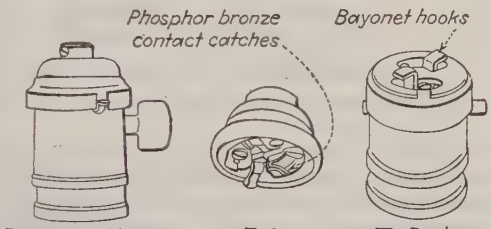


FIG. 194.—Porcelain snap-catch interchangeable lamp holders. (*General Electric Co.*)

125. The porcelain snap-catch interchangeable line of lamp holders (Fig. 194) are used in installations subjected to moisture, acid fumes, or other corroding influences. The bodies are fitted with two bayonet hooks which engage two flexible phosphor-bronze contacts in the cap or base.

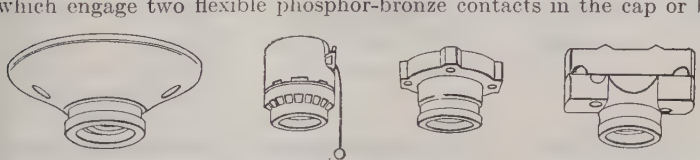


FIG. 195.—A few types of noninterchangeable lamp holders. (*General Electric Co.*)

The two parts are thus securely locked together when assembled but permit easy disassembly without affecting the wiring. The bayonet hooks and bronze contact catches provide the electrical connection between cap and body as well as supplying the means of mechanically support-

ing the body from the cap. The same general types of caps, bases, and bodies are included in this line as for the fluted-catch line. A porcelain line for the same type of applications is made with the cap and body fastened together by means of two screws.

126. Noninterchangeable lamp holders are made in a great variety of types to meet the requirements for lamp holders for show-window, show-

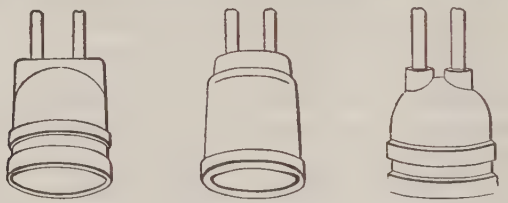


FIG. 196.—Weatherproof lamp holders. (*General Electric Co.*)

case, cove, trough, or reflector lighting; candelabra or intermediate-base lamps; lumiline or fluorescent lamps; mounting on outlet boxes; mounting in fixture canopies; lamp outlets in exposed wiring on insulators; and sign lighting, etc. Most of these holders are made of porcelain, but plastic materials are used to a limited extent. A few of the more common types are shown in Fig. 195.

127. Weatherproof lamp holders (Fig. 196) with one-piece porcelain,

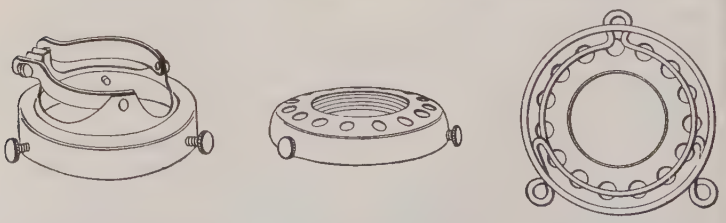


FIG. 197.—Shade holders. (*Pass & Seymour, Inc.*)

composition, or rubber cases are made with sealed-in leads for wet locations.

128. Shade Holders.—Many lamp holders have the body supplied with threads or grooves for engaging shade holders. Shade holders are made with openings of 2¼, 3¼, and 4 in. diameters for accommodating shades. Shades may be held to the shade holder with a wire spring or by means of screws (Fig. 197).

129. Insulating socket bushings must be used where a cord enters a socket, to protect it against abrasion and grounding against the shell. The most popular bushings are of hard rubber or of a compound resembling it. Patented bushings which automatically grip the cord by a wedging action can be purchased.

Most lamp holders of the pendant type are fitted with an approved bushing constructed as an integral part of the lamp-holder cap.

130. Rosettes are devices for supporting and connecting to the circuit the cord and sockets of flexible drop cords. They are made in different types for open wiring and for attaching to outlet boxes or moldings.

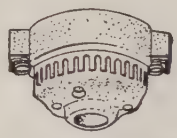


FIG. 198.—Cleat-base rosette for open wiring.

FIG. 199.—Rosette for attachment to outlet box.

Rosettes similar to the one shown in Fig. 198 are used for open wiring work, and ones similar to that of Fig. 199 for attachment to outlet boxes. The drop cord passes through the hole in the center and is attached to connections inside the body of the rosette. The connections should be relieved of any strain by making a knot in the wires just inside the rosette body. Fused rosettes were at one time employed, but they are no longer allowed by the National Electrical Code rules.

CAPACITORS

131. Capacitors are condensers of relatively large values of capacity used on power-distribution systems or in industrial plants for improving the power factor. Since many power companies include either low-power-factor penalties, kilovolt-ampere demand rates, or power-factor bonuses in their rate schedules, it is often economical for industrial consumers to install capacitors for power-factor improvement. These capacitors are connected across the line and neutralize the effect of lagging power-factor loads, thus reducing the current for a given kilowatt load. The amount of reactive kilovolt-amperes of capacitors required to raise the power factor to any given value can easily be determined from the chart of Fig. 200.

The best point to connect capacitors to the circuit depends upon cost considerations. Relatively small capacitor units may be connected at the individual loads, or the total capacitor kilovolt-amperes may be grouped at one point and connected to the main bus. Both of these methods are shown schematically in Fig. 201. Greater power-factor corrective effect for a given total capacitor kilovolt-ampere will result

with the capacitors located directly at each individual load, since the current is thereby reduced all the way from the load to the source. The first cost of an installation of individual capacitors will be greater, how-

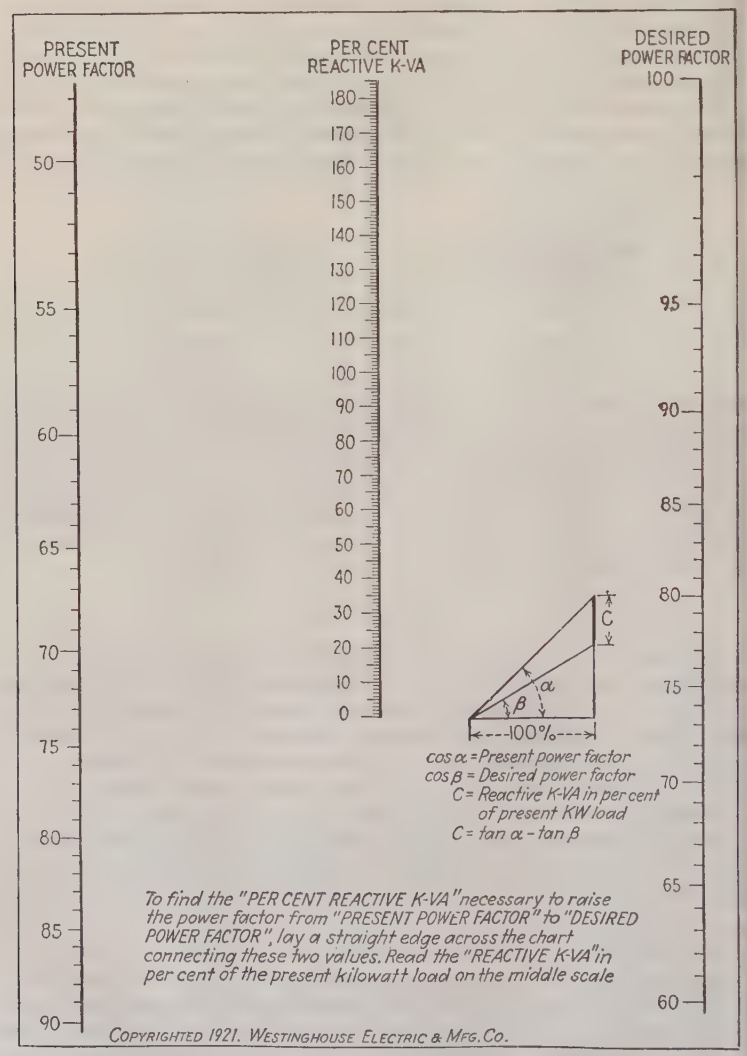


FIG. 200.—Chart for use in determining the percentage reactive kva required to raise the power factor to a desired value.

ever, than that for one unit of the same total kilovolt-amperes located at a central point. The greater saving in operating expense due to individual capacitors must be weighed against their increased first cost.

132. A complete capacitor bank is made up of the necessary standard units to give the desired kilovolt-amperes, connected in parallel with each other. Each unit consists of one or more cells enclosed in a hermetically sealed steel box (Fig. 202). The cells are aluminum-foil, paper-insulated capacitors impregnated with insulating oil or a noninflammable insulating medium. A noninflammable insulating medium is generally used, such as the General Electric Company's Pyranol or Westinghouse Electric Corporation's Inerteen. Standard units may be obtained with the cells internally connected for single-, two-, or

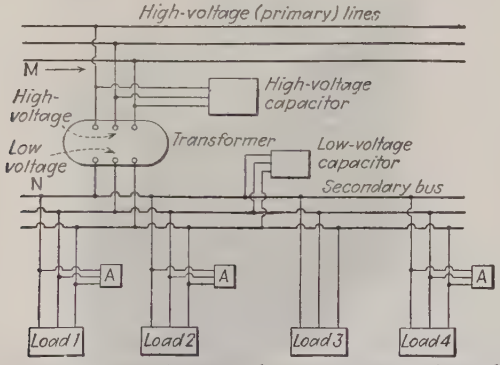


FIG. 201.—Location of capacitors on electric system. (*General Electric Co.*)

three-phase operation. The units may be of enclosed- or rack-type construction. The enclosed construction is made primarily for individual motor applications. It consists of a dusttight steel conduit box (Fig. 203) mounted on top of the hermetically sealed capacitor. The conduit box contains the terminals, discharge resistor, and fuses if desired (see Fig. 206). Rack-type banks consist of the required number of hermetically sealed capacitors with exposed terminals, supported on a steel rack. The complete structure may be provided with enclosing screens (Fig. 204), dusttight steel enclosing cases (Fig. 205), or a steel enclosing cabinet for outdoor installation. Each capacitor unit of the bank is individually fused, and the entire bank is provided with discharge resistors or coils inside the enclosure (see Fig. 208).

133. Drainage of Stored Charge.—When capacitors are disconnected from the supply they are generally in a charged state. Considerable energy is stored in the capacitor under this condition, and there is a voltage present between its terminals. If the capacitor were left in this charged state, a person servicing the equipment might receive a dangerous

shock, or the equipment might be damaged by an accidental short circuit. Therefore, all capacitors must be provided with a means of draining the stored charge (see Figs. 207 and 208). The National Electrical Code requires that the drainage equipment shall be so designed that it will discharge the capacitor to 50 volts or less within 1 min. after the capacitor is disconnected from the source of supply, in capacitors rated 600 volts or less, and in 5 min. in capacitors rated more than 600 volts. The discharge equipment may consist of resistors or inductive coils which are permanently connected to the terminals of the capacitor bank. If

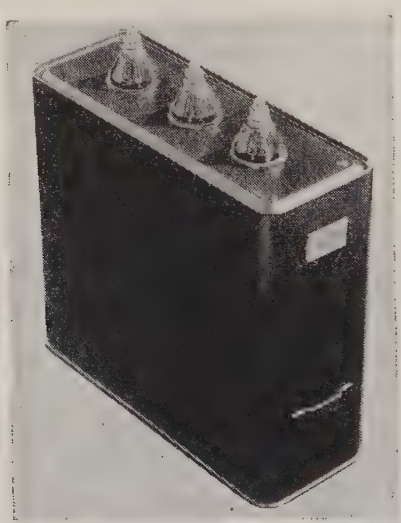


FIG. 202.—Three-phase capacitor unit enclosed in a hermetically sealed steel box. (*General Electric Co.*)

the discharge circuit is not permanently connected to the terminals of the capacitor bank, automatic means must be provided for connecting the capacitor to the discharge circuit on removal of supply voltage. When capacitors are connected directly to other equipment without switch or overcurrent device interposed, no discharge equipment is required, since the charge will drain off rapidly through the windings of the equipment (Fig. 206).

134. The National Electrical Code rules for size of conductors, overcurrent protection, and disconnecting means are given below:

1. Capacitor Rating.—The rating of capacitors that are connected on the load side of a motor overcurrent device shall not exceed the value required to raise the no-load power factor of the motor to unity. Capacitors of this maximum rating will usually result in a full-load power factor

of 95 to 98 per cent. The maximum capacitor ratings permitted for use with open-type, three-phase, 60-cycle induction motors are given in Table 28 of Div. 11.

2. Capacitor Circuits.—Capacitor circuits shall conform to the following:

a. **Conductor Ratings.**—The rating of capacitor circuit conductors shall be not less than 135 per cent of the rated current of the capacitor. The rating of conductors that connect a capacitor to the terminals of a motor or to motor circuit conductors shall be not less than one-third the rating of the motor circuit conductors, or the rating shall be determined as explained above if this method gives a greater value.

b. **Overcurrent Protection.**—An overcurrent device shall be provided in each ungrounded conductor except that an overcurrent device is not required for a capacitor connected on the load side of a motor overcurrent device. The rating or setting of the overcurrent device shall be as low as practicable without causing unnecessary opening of the circuit. A rating or setting of 165 to 250 per cent of the rated current of the capaci-

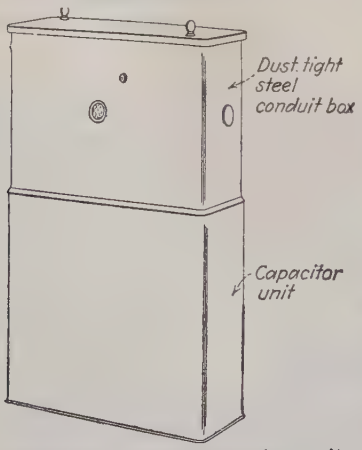


FIG. 203.—Enclosed capacitor unit.

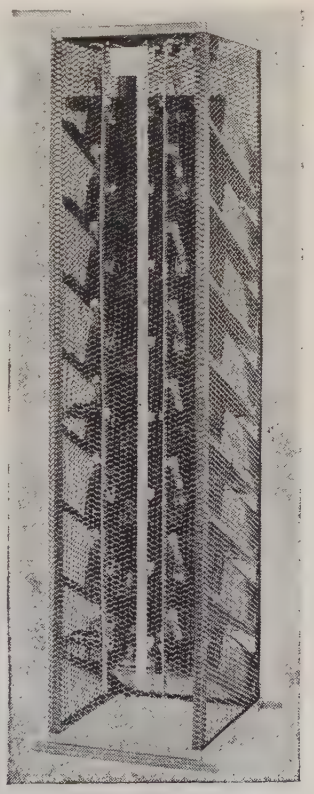


FIG. 204.—Typical small rack capacitor bank with enclosing screen for indoor service. (*General Electric Co.*)

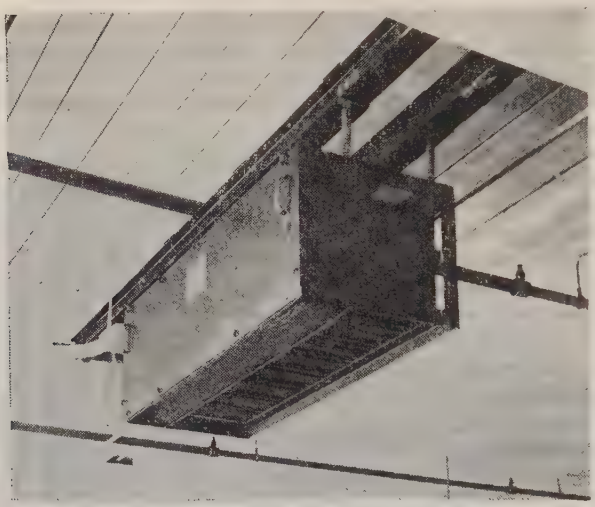


FIG. 205.—Typical small rack capacitor bank with dusttight enclosing case mounted from ceiling. (*General Electric Co.*)

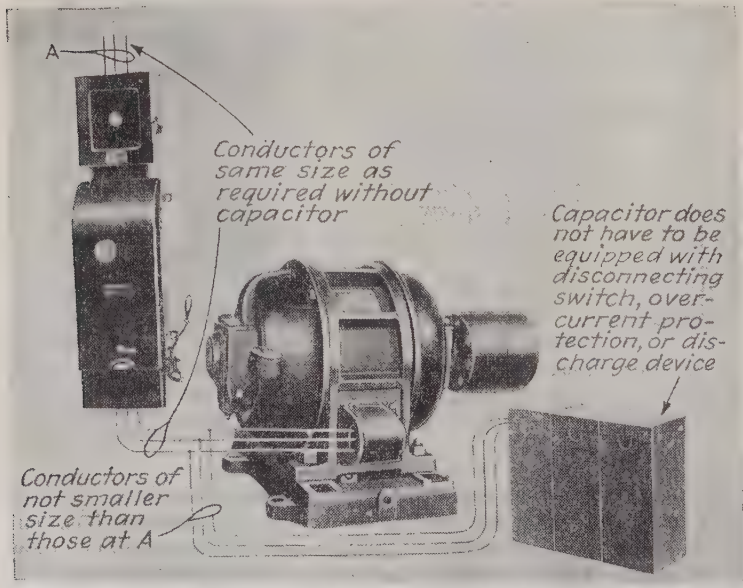


FIG. 206.—Schematic diagram of connections when an enclosed capacitor is installed at motor terminals. (*General Electric Co.*)

tor will be suitable under average conditions, although the setting or rating may have to exceed 250 per cent in some cases.

c. **Disconnecting Means.**—A disconnecting device shall be provided in each ungrounded conductor except that a disconnecting device is not required for a capacitor connected on the load side of a motor disconnecting device. The disconnecting device need not open all ungrounded conductors simultaneously. The disconnecting device may be used for disconnecting the capacitor from the line as a regular operating procedure. The continuous current-carrying capacity of the disconnecting device shall be not less than 135 per cent of the rated current of the capacitor.

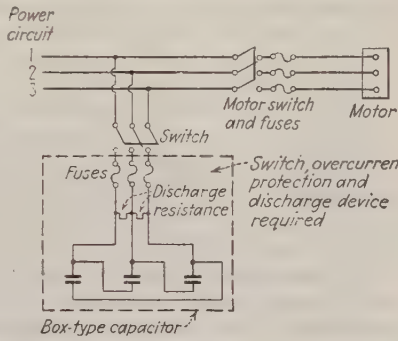


FIG. 207.—Connection diagram of enclosed capacitor unit, with fuses, installed on line side of motor switch.

3. Rating or Setting of the Motor Overcurrent Device.—If a motor installation includes a capacitor connected on the load side of the motor overcurrent device, and the overcurrent device used can be adjusted as explained below, the rating or setting of the motor overcurrent device shall be determined in accordance with Sec. **436** of Div. 7 except that, instead of using the

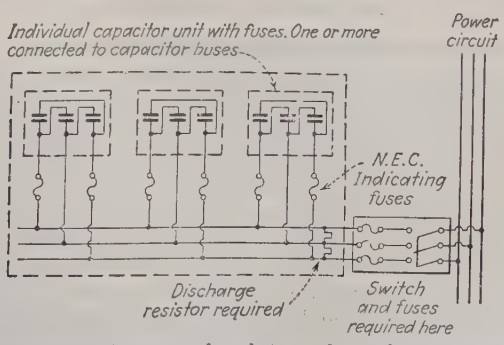


FIG. 208.—Connection diagram of rack type three-phase, 230-, 460-, or 575-volt capacitor installed in power circuit.

full-load rated current of the motor as provided in that section, a lower value corresponding with the improved power factor of the motor circuit shall be used. The reduction in the full-load current required is specified in Table 28 of Div. 11, for open-frame, three-phase, 60-cycle induction

motors. Section **444** of Div. **7** applies with respect to the rating of the motor circuit conductors.

4. Grounding.—Capacitor cases shall be grounded in accordance with Div. 9.

5. Guarding.—All live parts of capacitors which are connected to circuits of more than 600 volts between conductors and are accessible to unqualified persons, shall be enclosed or isolated. For isolation by elevation, see Sec. **30** of Div. 11.

6. Name Plate.—Each capacitor shall be provided with a name plate giving the maker's name, rated voltage, frequency, kva or amperes, number of phases, and, if liquid-filled, the amount of liquid in gallons, together with a statement that the liquid will or will not burn, as the case may be. The name plate shall indicate whether or not a capacitor unit has a discharge device inside the case.

135. Capacitors which are constructed with a liquid which will not burn may be located at any convenient location provided that they are not exposed to mechanical injury. If exposed to combustible dust or flyings or if located in vicinity of easily ignitible material, they must be enclosed in dusttight metal enclosures. Capacitors constructed with a liquid which will burn must be installed in vaults unless each container does not contain more than 3 gal. of liquid and the container is liquidtight without the use of solder. Solder, however, may be used to prevent the slight seepage of liquid. Vaults when required should be constructed so as to meet the same requirements as for transformers (see Div. 5).

BATTERIES—GENERAL

136. An electric battery is a device for producing an e.m.f. by chemical means. When such a source of e.m.f. is connected to a closed electric circuit, chemical energy is transformed into electrical energy. An e.m.f. will be produced by chemical means whenever two dissimilar solid conductors are immersed in a conducting liquid. The solid conductors are called electrodes, and the conducting liquid is called the electrolyte. Such a combination of chemicals resulting in the production of an e.m.f. is called a voltaic cell. A battery may consist of a single cell or a combination of cells. The voltage of a cell depends upon the material of the electrodes and the electrolyte and is independent of the dimensions of the cell. The current and power capacity of a cell are, however, directly dependent upon the dimensions of the cell and the weight of active material in the electrodes. Although there are an infinite number of different combinations of electrodes and electrolytes which will produce a voltaic cell, there are only a limited number of combinations which are practicable.

137. Classifications of Batteries.—For practical purposes, batteries may be classified as primary and secondary. A **primary battery** is

used only for discharge (conversion of chemical energy into electrical energy). As such a battery is discharged, the material of one of the electrodes goes into solution in the electrolyte. The electrode is thus consumed, and the character of the electrolyte altered so that with primary batteries it is necessary to renew from time to time both the electrode which goes into solution and the electrolyte. A **secondary battery** is alternately discharged and charged. As a battery discharges, the electrodes and electrolyte undergo chemical changes. After a secondary battery has been discharged, the electrodes and electrolyte can be restored to their original charged condition by passing a current through the battery in the reverse direction from that of discharge. In charging a battery, electrical energy is transformed into chemical energy. **Secondary batteries** are generally called **storage batteries.**

138. The internal resistance of batteries is the resistance offered to the flow of current inside the battery, due to its electrodes and electrolyte. Owing to this internal resistance, the voltage at the terminals of a battery is less when it is discharging than when it is on open circuit. The internal resistance of a battery will change with the condition of discharge. As the battery discharges, the internal resistance increases, so that the terminal voltage decreases as the battery discharges. The terminal voltage of a battery is thus dependent upon the rate of discharge and the length of discharge. The voltage of a battery will decrease rather slowly as the battery discharges until nearly all the active material of the electrode has gone into solution. The battery is then discharged, and the voltage will drop rapidly to a very low value with any further attempt to discharge.

PRIMARY BATTERIES

139. The standard Daniell's cell is a primary cell which has an e.m.f. which is practically 1 volt when delivering a constant current. There are many forms of Daniell's cell, each of which is particularly adapted to certain service but all having very nearly the same e.m.f. (1.07 + volts). The e.m.f. is not changed appreciably by the degree of concentration of the solutions, by the temperature, by the resistance, or by the purity of the zinc or copper, etc. In short, it makes a very good rough-and-ready standard.

A very good model is that used by the British Post Office. The jar is made with two compartments: one containing a porous cup immersed in water, in which are placed a copper plate and crystals of copper sulphate, the other containing a zinc plate and a 50 per cent saturated solution of zinc sulphate. The zinc plate is fastened so as to be just clear of the solution, and a pencil of zinc is placed in the bottom. When in use, the porous cup is placed in the second compartment, thus raising the level of the zinc solution so as to immerse the zinc. Under working conditions the e.m.f. is about 1.07 volts; when new it is about 1.079 volts.

140. The gravity-type primary cell, which is used in telegraph work, is suitable for closed-circuit work but should not be used for applications where it is apt to stand for a long time on open circuit.

141. In setting up the gravity cell, place the copper electrode (−) in the bottom of the jar and pour in about 3 lb. of copper sulphate crystals. Next place the zinc electrode (+) and fill with water to cover the zinc; to the water add a tablespoonful of sulphuric acid. Cover the electrolyte with a layer of pure mineral oil, which should be free from naphtha or acid and have a flash point above 400°F. If the oil is not used, the creeping can be stopped by dipping the edge of the jar in hot paraffin. When the cell is thus set up it should be short circuited for a day or two to form zinc sulphate which will protect the zinc electrode; this preliminary run also reduces the internal resistance. The temperature of the cells should be kept above 70°F., since the resistance increases rapidly with a decrease in temperature.

The internal resistance of the gravity cell is ordinarily from 2 to 3 ohms. A blue color in the bottom of the cell denotes a good condition, but a brown color shows that the zinc is deteriorating. When renewing the copper sulphate it is best to empty the cell and set it up with a completely new electrolyte The blue line, which marks the boundary between the copper sulphate and the zinc sulphate, should stand about halfway between the electrodes. If it comes too close to the zinc, some of the copper sulphate can be siphoned out, or the cell can be short-circuited so as to produce more zinc sulphate. If the blue line goes too low, some water and crystals of copper sulphate should be added.

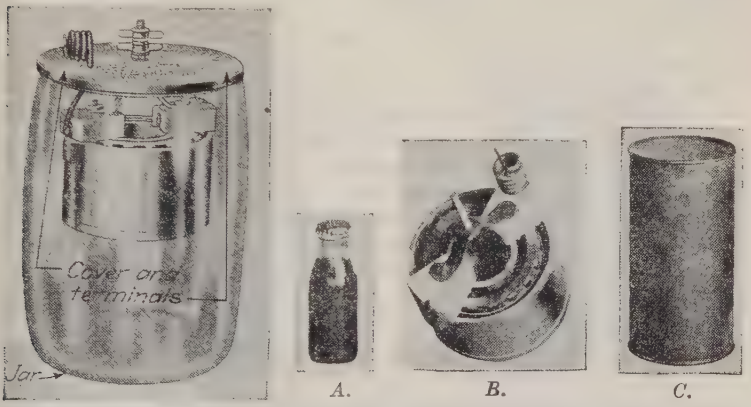
142. The Fuller cell is well adapted to telephone work or any intermittent work. It can stand on open circuit for several months at a time without any appreciable deterioration.

143. The Fuller cell is set up as follows: Mix the electrolyte by adding 6 oz. of potassium bichromate and 17 oz. of sulphuric acid to 56 oz. of soft water; pour this mixture into a suitable glass jar. Into a suitable porous cup put 1 teaspoonful of mercury and 2 teaspoonfuls of salt; place the cup and a zinc electrode in the glass jar and fill to within 2 in. of the top with soft water. Put on the cover, insert a carbon electrode, and the cell is ready for use.

The color of the solution is orange when in working order. The resistance varies from 0.5 to 4 ohms depending upon the condition and dimensions of the porous cup and upon the concentration of the solution.

144. The Lalande cell, frequently called the caustic soda cell, is suitable for either open- or closed-circuit work. The mechanical construction of this cell is especially good. The positive pole is a plate of compressed oxide of copper, the surfaces of which are reduced to metallic copper to improve the conductivity. This form of plate also acts as a depolarizer. The negative pole is of pure zinc amalgamated throughout by adding mercury when the casting is made. The electrolyte is a solution of

caustic soda. The top of the solution is covered with a heavy mineral oil to prevent the solution from evaporating.

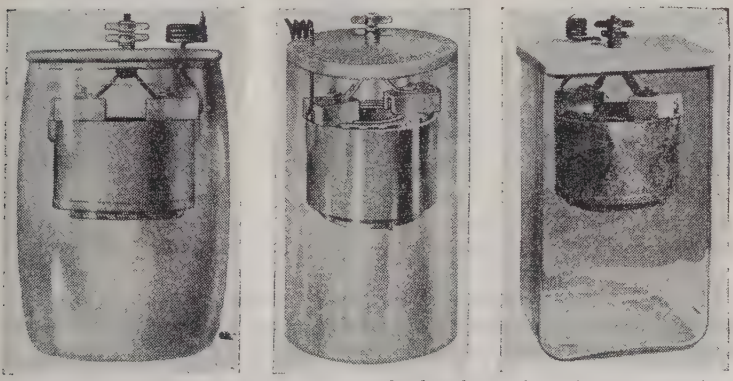


I. Assembled cell.

A. B. C.

II. Renewal parts
A. Bottle of battery oil
B. Cylinder element
C. Can of caustic soda

FIG. 209.—Unit cylinder type of caustic soda primary battery. (*Waterbury Battery Co.*)



I. In barrel-shaped jar; size over all, $7\frac{1}{8}$ in. diameter by $11\frac{3}{4}$ in. high

II. In cylindrical jar; size over all, $6\frac{7}{8}$ in. diameter by $12\frac{3}{4}$ in. high

III. In rectangular jar; size over all, $5\frac{9}{16}$ by $6\frac{9}{16}$ by $12\frac{3}{8}$ in.

FIG. 210.—Types of jar for Waterbury unit cylinder primary batteries.

The e.m.f. of all types and sizes of caustic soda cell initially is approximately 0.90 volt per cell. The voltage on closed circuit will depend upon the rate of discharge and the size of cell. Typical voltage characteristics

are shown in Fig. 216. The larger sizes having lower internal resistance will of course have a higher voltage for a given rate of discharge than the smaller cells under similar conditions. For ordinary purposes, however, it is safe to figure a mean effective voltage of approximately 0.67 volt per cell at normal temperature.

145. Primary batteries of the caustic soda type are manufactured by the Waterbury Battery Co. in several types to meet the requirements of various kinds of service as given in the following list.

Railroad automatic semaphore signals.
Light signals, highway-crossing bells.
Telephone and telegraph systems.
Fire and burglar alarms, police signals.
Annunciators, scientific apparatus.
Schoolhouse systems.
Gas-engine ignition.
Program and self-winding clocks.

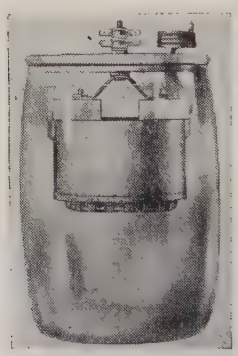


FIG. 211.—Appearance at about 375 amp.-hr.

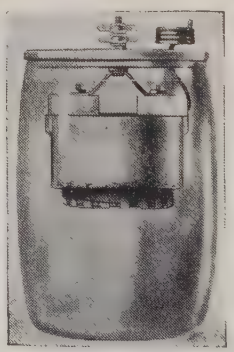


FIG. 212.—Appearance at about 475 amp.-hr.

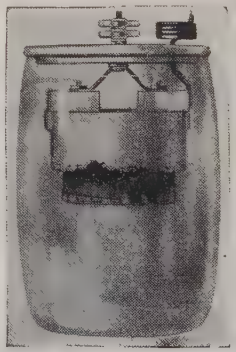


FIG. 213.—Appearance at about 500 amp.-hr.

The unit-cylinder type of cell (Fig. 209) consists of permanent or inactive parts—jar, cover, terminal nuts, and washers—and active or renewal parts—cylinder element, can of caustic soda, and bottle of battery oil. They are available in different types of glass jars as shown in Fig. 210. Cells of 250-, 300-, 500-, and 1,000-amp.-hr. capacity are available. These batteries are so designed that visual indication is given of the degree of exhaustion of the cell, as explained below:

1. The first indication of approaching exhaustion occurs at about 375 amp.-hr. when, under ordinary conditions of discharge, small holes appear above the reinforcing rib and gradually encircle the zinc (see Fig. 211).

2. From that point the zinc is gradually consumed at the bottom, until the lower rib has been eaten away, which will be at about 475 amp.-hr. (see Fig. 212).

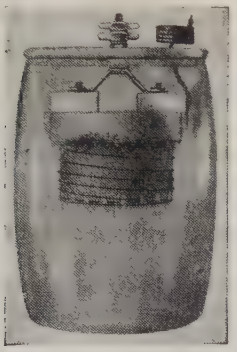


FIG. 214.—Completely exhausted.

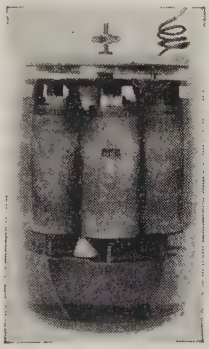


FIG. 215.— 5 0 0 -amp.-hr. high-amperage caustic soda cell complete. (*Waterbury Battery Co.*)

3. The zinc is then consumed from the bottom upward until about 2 in. only of the zinc remains (see Fig. 213) when the rated capacity, 500 amp.-hr., has been used; but there is still considerable capacity remaining, the amount depending upon the nature of the work and general service conditions.

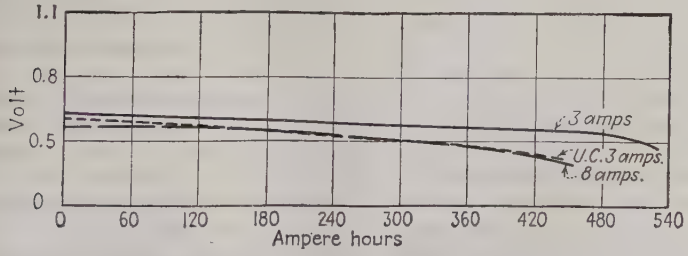


FIG. 216.—Comparison of the performance of the new 500-amp.-hr. battery on continuous discharge with that of the unit cylinder ("U. C.") cell (broken line). Temperature of electrolyte 1°C.

4. After the small holes appear (see Fig. 211) there will be approximately one-quarter of the rated life of the cell still available for use.

After a substantial part of the zinc has disappeared (see Fig. 213) the cell must be watched carefully to procure maximum life without failure,

taking into consideration the class of service for which the battery is being used.

A high-amperage cell (Fig. 215) is made for railroad signal work for installations which require a cell capable of maintaining its voltage at high-amperage discharge rates. A comparison of the voltage-discharge characteristics of the regular cells and the high-amperage cell is given in Fig. 216.

146. The Following Instructions Are Given by the Waterbury Battery Co. for Setting Up or Renewing Their Cells.—Remove all packing material from the new elements; then clean the jars and examine them for cracks. Cracked jars should not be used.

Mixing the Solution.—Fill each jar to $1\frac{3}{4}$ in. from top with clear water. Disregard any ridges or colored lines in the jars, as they may not be properly located for unit-cylinder elements.

The ordinary water to be had at most locations should be suitable for all practical purposes, but water containing an excess of iron, lime, copper, sulphur, etc., should not be used.

Pour contents of one can of soda in each jar slowly and stir with a slender stick until soda is thoroughly dissolved.

It is of the utmost importance that the right amount of water be used with each cell, together with the full can of soda of the special grade supplied with all Waterbury complete cells and renewals. The capacity and the density of the solution depend upon the use of a sufficient amount and the proper proportioning of the soda and water. This is one of the most important elements in the operation of the battery.

Caution.—The jar should be filled with water to $1\frac{3}{4}$ in. from the top before adding any of the soda, and care should be used in mixing the solution to avoid splashing or spilling after soda is added, as it will burn the skin or clothing. If it is splashed on the skin, remove quickly by washing with water or vinegar. The soda should be thoroughly dissolved before the elements are inserted.

Inserting the Elements.—Fasten the new elements securely to covers and immerse slowly in the solution. It is not necessary to wait for the solution to cool, but it is better to do so if the cells are not to be placed on discharge immediately after being set up.

Pouring In the Oil.—After the elements have been immersed, move covers slightly and pour contents of one bottle of oil in each cell.

The oil should not be omitted, and it should not be poured on the solution before immersing the elements. If dry copper oxide elements are passed through the oil, some of the oil may be absorbed, and this will impair the efficiency of the element.

When cells are set up or renewed in accordance with these directions, they are ready for use as soon as they are properly connected to the circuit. No short-circuit or preliminary discharge is necessary, as the compressed copper oxide elements are wound with zinc-coated wire, which

ensures good internal conductivity as soon as the elements are immersed in the solution.

147. The Waterbury Telecell (Fig. 217) was designed to fill the need of a primary battery cell that could be absolutely depended upon to deliver relatively large amounts of current continuously or intermittently, that would not dry out or lose capacity in stock or in service, and that would be flexible in its service applications.

This is a cell assembled ready to use, except for the addition of water to form the electrolyte.

All elements are sealed in an airtight glass jar, making a self-contained compact unit but slightly larger than the standard-sized dry cell—2⅞ in. in diameter by 9 in. high.

The Telecell is especially applicable to telephone or other service where dry cells are generally used. It is, however, equally suitable for open circuit (intermittent discharge) or closed circuit (continuous discharge) giving excellent service under wide variations in discharge rates and temperatures as well as under normal conditions. The solution will stand temperatures lower than −20°F. It is particularly well adapted for continuous closed circuit work, because its low internal resistance and effective depolarization result in the voltage, at normal discharge rates, being practically constant throughout the life of the cells. It is also highly economical for open-circuit work because of the higher voltage available for intermittent contacts of short duration.

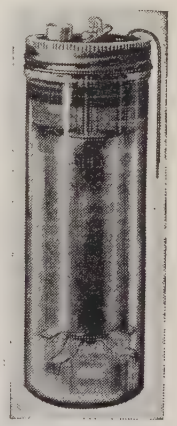


FIG. 217.—Waterbury Telecell; size over all, 2⅞ in. diameter by 9 in. high.

The long life of the Telecell makes for less frequent replacement, thereby effecting considerable saving in maintenance costs as, in many instances, the labor and other costs incidental to dry-cell replacement are more than the cost of the cells. The Telecell gives an advance indication of approaching exhaustion which assists in reducing maintenance and enables the full life of the cell to be utilized.

147A. The Leclanché cell is adapted only to intermittent work such as bells, telephones, etc. It is cheap and easy to maintain.

147B. The Laclanché cell is set up as follows: Put 3 or 4 oz. of sal ammoniac in the jar; pour about one-third full of water and stir until the sal ammoniac is all dissolved; place the carbon electrode in the porous cup and pack manganese dioxide and crumbled carbon around it; then insert the porous cup and the zinc electrode into the jar, and the cell is ready for use.

Practically the only attendance consists in renewing the evaporated water. The zinc is replaced when worn out. When it becomes necessary to add sal ammoniac the solution should be thrown out and a new one

made. If the porous cell becomes clogged, soaking in warm water will improve it.

The resistance depends upon the dimensions of the electrodes, the state of the porous cup, and the condition of the cell. Under proper working conditions and with a carbon electrode having about 8 sq. in. of surface, the resistance will be about 1.5 ohm.

147C. The modern dry cell is a modification of the Leclanché cell. The chief difference is that only sufficient water is added to its electrolyte to moisten an absorbent lining of pulpboard, blotting paper, cheesecloth, or starch paste. This lining separates the positive and negative poles. The negative pole, which also serves as a container, is usually a hollow sheet-zinc cylinder, 6 in. high and 2½ in. in diam. The bottom of this cylinder is also, usually, made of zinc. A majority of the dry cells made in the United States are, probably, of these dimensions. The positive pole is a carbon rod which may be either smooth cylindrical or fluted. The absorbent layer above mentioned is placed next to the zinc and is saturated with a solution of sal ammoniac and zinc chloride. The space between this lining and the carbon electrode is filled with a mixture of granulated carbon and manganese dioxide, the later being the depolarizer. The top of each cell is usually sealed with a pitch compound. When exhausted, the cell is thrown away. Frequently the life may be extended by punching a hole in the top and pouring in water.

STORAGE BATTERIES—GENERAL

148. A storage battery is a device which may be used repeatedly for storing energy at one time in the form of chemical energy for use at another time in the form of electrical energy. It consists of two kinds of plates bearing the necessary electrochemically active materials immersed in a proper solution. The solution is called the electrolyte. Charging a battery consists of connecting the two terminals to a d-c supply of proper polarity for a sufficient length of time. Electrical energy is delivered by the d-c supply to the battery, in which it produces certain chemical reactions so that the energy is converted into chemical energy. If a charged battery has its two terminals connected through a closed external electric circuit, the active materials of the plate will react chemically with the electrolyte, producing a flow of current in the circuit. This conversion of chemical energy into electrical energy is called discharging the battery. Charging is the process of putting energy into the battery (delivering energy to the battery), while discharging is the process of taking energy from the battery (battery delivering energy to external electric circuit).

149. Storage cell is the name given to the fundamental unit of any storage battery. It consists of one positive plate or a group of positive plates electrically connected together, one negative plate or a group of negative plates electrically connected together, separators, electrolyte,

and a suitable container. A storage battery may consist of a single cell or a group of cells electrically interconnected.

150. Types of Storage Batteries.—Storage batteries may be classified in two ways as follows:

1. According to fundamental type of service for which it is suitable.
   a. Stationary.
   b. Portable.
2. According to fundamental materials of construction.
   a. Lead-acid.
   b. Nickel-iron-alkaline.

Stationary batteries are those designed for service in a permanent location.

Portable batteries are those designed for service requiring the transportation of the batteries during service.

151. Storage-battery Terminology.—The following definitions of terms are taken from the standards of the American Institute of Electrical Engineers.

Active Materials.—Materials of plates reacting chemically to produce electrical energy during the discharge. The active materials of storage cells are restored to their original composition, in the charged condition, by oxidation or reduction processes produced by the charging current.

Grid.—A metallic framework for conducting the electric current and supporting the active material.[1]

Positive Plate.—The grid and active material from which the current flows to the external circuit when the battery is discharging.

Negative Plate.—The grid and active material to which the current flows from the external circuit when the battery is discharging.

Electrolyte.—An aqueous solution of sulphuric acid used in lead cells and of certain hydroxides used in nickel-iron-alkaline cells.

Separator.—A device for preventing metallic contact between the plates of opposite polarity within the cell.

Group.—Assembly of a set of plates of the same polarity for one cell.

Element.—The positive and negative groups with separators assembled for a cell.

Couple.—The element of a cell containing two plates, one positive and one negative. This term is also applied to a positive and negative plate connected together as one unit for installation in adjacent cells.

Jar.—The container for the element and electrolyte of a cell. Specifically a jar for lead-acid cells is usually of hard-rubber composition or glass; but for nickel-iron-alkaline cells it is a nickel-plated steel container frequently referred to as a "can."

Tank.—A lead container, supported by wood, for the element and electrolyte of a cell. This is restricted to some relatively large types of cells.

[1] In certain types of batteries the active material is enclosed in containers which are held in place by the grid.

Case.—A container for several cells. Specifically wood cases are containers for cells in individual jars; rubber or composition cases are provided with compartments for the cells.

Tray.—A support or container for one or more cells.

Terminal Posts.—The points of the cell or battery to which the external circuit is connected.

End Cells.—The cells of a battery which may be cut in or out of the circuit for the purpose of adjusting the battery voltage.

Pilot Cell.—A selected cell whose temperature, voltage, and specific gravity of electrolyte are assumed to indicate the condition of the entire battery.

Ampere-hour Capacity.—The number of ampere-hours which can be delivered by a cell or battery under specified conditions as to temperature, rate of discharge, and final voltage.

Watt-hour Capacity.—The number of watt-hours which can be delivered by a cell or battery under specified conditions as to temperature, rate of discharge, and final voltage.

Time Rate.—The rate in amperes at which a battery will be fully discharged in a specified time, under specified conditions of temperature and final voltage, as, for example, the 8-hr. rate or the 20-min. rate.

Open-circuit Voltage.—The voltage of a cell or battery at its terminals when no current is flowing. For the purpose of measurement, the small current required for the operation of a voltmeter is usually negligible.

Closed-circuit Voltage.—The voltage at the terminals of a cell or battery when current is flowing.

Average Voltage.—The average value of the voltage during the period of charge or discharge. It is conveniently obtained from the time integral of the voltage curve.

Initial Voltage.—The voltage of a cell or battery at the beginning of a charge or discharge. It is usually taken after the current has been flowing for a sufficient period of time for the rate of change of voltage to become practically constant.

Final Voltage.—The prescribed voltage upon reaching which the discharge is considered complete. The final voltage is usually chosen so that the useful capacity of the cell is realized. Final voltages vary with the type of battery, the rate of the discharge, temperature, and the service in which the battery is used.

Polarity.—An electrical condition determining the direction in which current tends to flow. By common usage the discharge current is said to flow from the positive or peroxide plate through the external circuit. In a nickel-iron-alkaline battery the positive plate is that containing nickel peroxide.

Charge.—The conversion of electrical energy into chemical energy within the cell or battery. This consists of the restoration of the active materials by passing a unidirectional current through the cell or battery in

the opposite direction to that of the discharge. A cell or battery which is said to be "charged" is understood to be fully charged.

Charging Rate.—The current expressed in amperes at which a battery is charged.

Constant-current Charge.—A charge in which the current is maintained at constant value. For some types of lead batteries this may involve two rates called the starting and the finishing rates.

Constant-voltage Charge.—A charge in which the voltage at the terminals of the battery is held at a constant value. A modified constant-voltage system is usually one in which the voltage of the charging circuit is held substantially constant, but in which a fixed resistance is inserted in the battery circuit producing a rising voltage characteristic at the battery terminals as the charge progresses. This term is also applied to other methods for producing automatically a similar characteristic.

Boost Charge.—A partial charge, usually at a high rate for a short period.

Equalizing Charge.—An extended charge given to a battery to ensure the complete restoration of the active materials in all the plates of all the cells.

Trickle Charge.—A continuous charge at low rate approximately equal to the internal losses and suitable to maintain the battery in a fully charged condition. This term is also applied to very low rates of charge suitable not only for compensating for internal losses but to restore intermittent discharges of small amount delivered from time to time to the load circuit.

Finishing Rate.—The rate of charge expressed in amperes to which the charging current for some types of lead batteries is reduced near the end of charge to prevent excessive gassing and temperature rise.

Discharge.—The conversion of the chemical energy of the battery into electrical energy.

Reversal.—Change in normal polarity of a storage cell.

Local Action or Self-discharge.—The internal loss of charge which goes on continuously within a cell regardless of connections to an external circuit.

Floating.—A method of operation in which a constant voltage is applied to the battery terminals sufficient to maintain an approximately constant state of charge.

Specific Gravity of Electrolyte.—The electrolyte of lead-acid batteries increases in concentration to a fixed maximum value during charge and decreases during discharge. The concentration is usually expressed as the specific gravity of the solution. This variation of specific gravity of the solution affords an approximate indication of the state of charge.

The specific gravity of the electrolyte in nickel-iron-alkaline batteries does not change appreciably during charge or discharge and therefore does not indicate the state of charge. The specific gravities, however, are indication of the electrochemical usefulness of the electrolyte.

Gassing.—The evolution of oxygen or hydrogen, or both.

Efficiency.—The ratio of the output of a cell or battery to the input required to restore the initial state of charge under specified conditions of temperature, current rate, and final voltage.

Ampere-hour Efficiency (Electrochemical Efficiency).—The ratio of the ampere-hours output to the ampere-hours of the recharge.

Volt Efficiency.—The ratio of the average voltage during the discharge to the average voltage during the recharge.

Watt-hour Efficiency (Energy Efficiency).—The ratio of the watt-hours output to the watt-hours of the recharge.

General.—Batteries are usually rated in terms of the number of ampere-hours which they are capable of delivering when fully charged and under specified conditions as to temperature, rate of discharge, and final voltage. For different classes of service, different time rates (see definition of time rate) are frequently used. For comparing the capacities of batteries of different size but of the same general design, it is customary to use the same time rate, and a comparison based on the different lengths of time they will discharge at the same rate is not recommended, as it is misleading.

Misrating.—A battery which fails to deliver its rated capacity on the third successive measured cycle of charge and discharge under specified current rates, temperature of electrolyte, specific gravity, and final voltage shall be considered to be improperly rated.

LEAD-ACID BATTERIES

152. Lead-acid Batteries.[1]—In the charged condition the active materials consist of lead peroxide on the positive plate and sponge lead on the negative plate. The electrolyte is a mixture of sulphuric acid and water. The strength of the electrolyte is measured in terms of specific gravity, which is the ratio of the weight of a given volume of electrolyte to an equal volume of water. Concentrated sulphuric acid has a specific gravity of about 1.830; water has a specific gravity of 1.000. The acid and water are mixed in a proportion to give the specific gravity desired. For example, an acid manufacturer to supply electrolyte of 1.210 gravity will mix roughly about 1 part of concentrated acid to 4 parts of water.

In a fully charged battery all the active material of the positive plates is lead peroxide, and that of the negative plates is pure sponge lead. In a fully charged battery all the acid is in the electrolyte, and the specific gravity is at its maximum value. The active material of both the positive and negative plates is porous so that it has absorption qualities similar to a sponge, and the pores are therefore filled with some of the battery solution. As the battery discharges, the acid, which is in the pores of the plates, separates from the electrolyte, forming a chemical combination

[1] A large portion of the following information in this section on lead-acid batteries has been taken from the literature of the Electric Storage Battery Co.

with the active material, changing it to lead sulphate. As the discharge continues, additional acid is drawn or diffused from the electrolyte into the pores of the plates, and further sulphate is formed. It can be readily understood that, as this process continues, the specific gravity of the electrolyte will gradually decrease, because the proportion of acid is decreasing. On charge the reverse action takes place: the acid in the sulphated active material is driven out and back into the electrolyte. This return of the acid to the electrolyte increases the specific gravity, so that it will continue to rise until all the acid is driven out of the plates and back into the electrolyte. After all the acid is driven back into the electrolyte, further charging will not raise the specific gravity any higher, as all the acid in the cells is in the electrolyte, and the battery is said to be fully charged. The material of the positives is again lead peroxide and that of the negatives is spongy lead; the specific gravity is maximum.

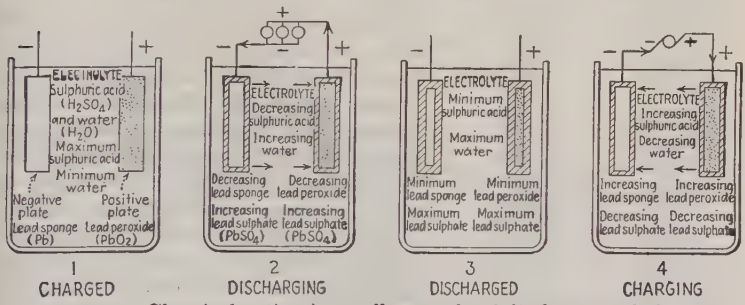


FIG. 218.—Chemical action in a cell on cycle of discharge and charge.

Practically speaking, on discharge the plates absorb acid, and the specific gravity of the electrolyte decreases. On the charge the plates return the absorbed acid to the electrolyte and the specific gravity increases. Figure 218, showing a cell charged, discharging, discharged, and charging, illustrates clearly the chemical action which takes place on charge and discharge:

When a cell is fully charged [Fig. 218(1) of the diagram], the negative plate is lead sponge, Pb, the positive plate is lead peroxide, PbO_2, and the specific gravity of the electrolyte (sulphuric acid, H_2SO_4, and water, H_2O), is at its maximum. Chemical energy is stored in the cell in this condition.

When a cell is put on discharge [Fig. 218(2)], the H_2SO_4 of the acid is divided into H_2 and SO_4. The H_2 passes in the direction of the current to the positive plates and combines with some of the oxygen of the lead peroxide and forms H_2O; the SO_4 combines with the liberated Pb of the positive plate to form lead sulphate. The SO_4 also forms lead sulphate at the negative or lead sponge (Pb) plate. As the discharge progresses,

both plates finally contain considerable lead sulphate, $PbSO_4$ [see Fig. 218(3)]. The water formed has diluted the acid, lowering the specific gravity of the electrolyte. When the plates are entirely sulphated, current will cease, since the plates are then identical, and any active electric cell requires two dissimilar plates in electrolyte. In common practice, however, the discharge is always stopped before the plates have become entirely reduced to lead sulphate.

During charge [Fig. 218(4)], the lead sulphate, $PbSO_4$, on the positive plate is converted into lead peroxide, PbO_2, while the lead sulphate on the negative plate is converted into sponge lead, Pb, and the electrolyte gradually becomes stronger as the SO_4 from the plates combines with hydrogen from the water to form acid, H_2SO_4, until no more sulphate remains and all the acid has been returned to the electrolyte. It will then be of the same strength as before the discharge, and the same acid will be ready to be used over again during the next discharge.

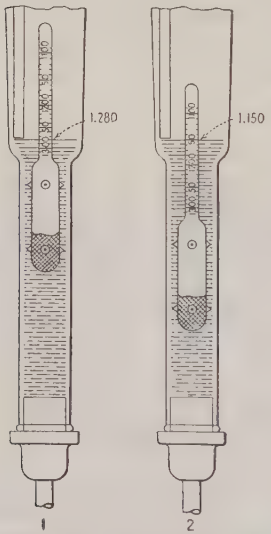


FIG. 219.—Illustrating use of hydrometer in determining specific gravity of electrolyte.

153. Change in Electrolyte during Charge and Discharge.—During discharge, as stated in Sec. **152,** some of the acid leaves the electrolyte and combines with the plates. During charge, the acid which has been absorbed by the plates is driven back into the electrolyte. When all the acid has been driven back into the electrolyte, the battery is fully charged.

When all the acid has been driven into the electrolyte, the electrolyte is stronger than when some of the acid is in the plates. This strength is measured in terms of specific gravity. The specific gravity of the electrolyte, therefore, changes as the battery charges or discharges. It falls on discharge and rises on charge. It is, then, an excellent indication of the state of charge of a battery, being greatest when the cell is fully charged and least when discharged.

The difference between the full charge and discharge values of the gravity depends upon the type of cell under consideration. For example, for the type of cell in use in starting work in automobiles, the full-charge gravity in temperate climates is 1.280, discharged 1.150.

The specific gravity of the electrolyte is readily determined by means of a float called a hydrometer. With a high specific gravity, the hydrometer or float does not sink so far in the electrolyte as it does when the specific gravity is low (see Fig. 219).

154. Voltage Characteristics.—The voltage of each cell is approximately 2 volts on an open circuit but is higher than this when the battery is being charged and lower when being discharged. The nominal voltage of a battery is, therefore, the number of cells multiplied by two.

The voltage at any time on discharge or charge depends upon several factors, such as the current rate, the state of charge or discharge, and the temperature. No general averages to cover all conditions can therefore be given. In usual 6- to 8-hr. discharge service, the average cell voltage (Sec. **151**) during discharge is roughly 1.95 volts with a final voltage of about 1.75 volts. As soon as the cell is put on charge its voltage rises to about 2.15 volts and then increases during charge until at the end it is between 2.4 and 2.7, depending upon local conditions. The average voltage during the entire charge is usually considered to be 2.33 volts.

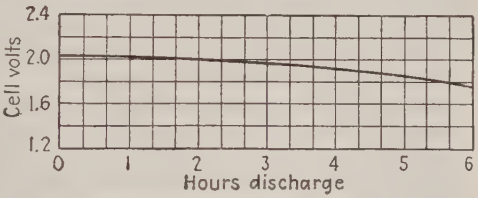


FIG. 220.—Type MVM Exide—Ironclad discharge characteristics at the 6-hr. rate. (*The Electric Storage Battery Co.*)

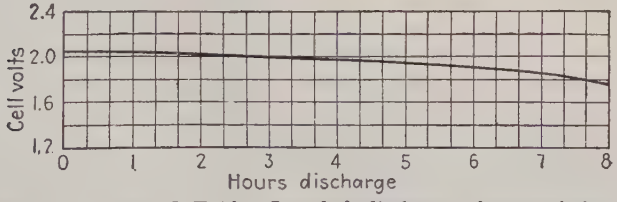


FIG. 221.—Type MVM Exide—Ironclad discharge characteristics at the 8-hr. rate. (*The Electric Storage Battery Co.*)

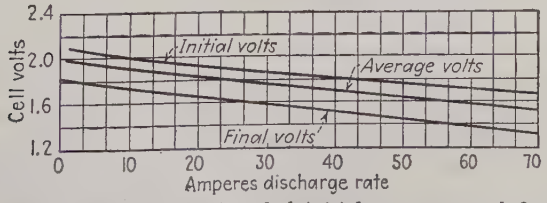


FIG. 222.—Type MVM Exide-Ironclad initial, average, and final volts at various discharge rates. (*The Electric Storage Battery Co.*)

Typical voltage-discharge characteristics are given in Figs. 220 and 221. The effect of the discharge rate upon the voltage characteristics is shown in Fig. 222.

155. High discharge rates (amperes) are often confused with over-discharge (too many ampere-hours taken out).—A lead-acid battery of the type sold under the trade names Exide, Chloride, and Ironclad may be discharged, without injury to the plates, at any rate of current that it will deliver. The maximum permissible rate of discharge is limited only by the current-carrying ability of the wiring, motor, or other apparatus to which the battery is connected or by the current-carrying ability of the cell terminals and connectors and not by the plates themselves.

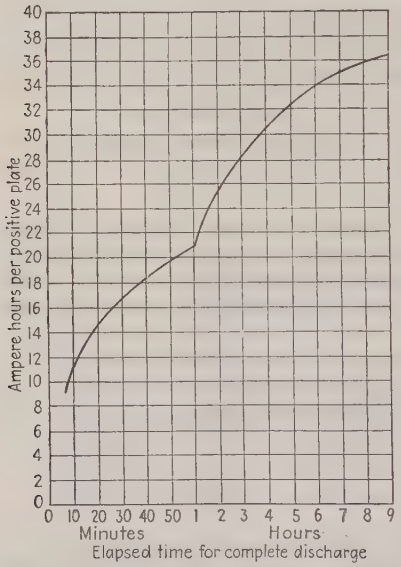


FIG. 223.—Curve illustrating effect of discharge rate upon available ampere-hour capacity of lead-acid storage batteries. (*The Electric Storage Battery Co.*)

156. Rating of Lead-acid Batteries.—All batteries are given a normal-ampere-hour-capacity rating based on a certain time rate of discharge under specified conditions of temperatures and final voltage. For example, a certain battery may have an 8-hr. rating of 1,000 amp.-hr. discharging to 1.75 volts per cell at a temperature of 77°F.

The ampere-hour capacity of a battery depends upon the amount of available active material in the plates that may be reached by the electrolyte, the amount of sulphuric acid in the electrolyte, the rate of discharge, and the allowable safe limit of discharge. To produce an ampere-hour of electricity on discharge requires the combination of a certain amount of sponge lead (negative active material) and a certain amount of peroxide of lead (positive active material) with a certain amount of sulphuric acid from the electrolyte. The allowable rating therefore depends upon the construction of the plates and the number of plates that are constructed in parallel on each side of the battery.

157. Effect of Discharge Rates on Discharge Capacity of Lead-acid Batteries.—The useful ampere-hour capacity of a storage battery depends on the rate of discharge and is greater for a long low rate or intermittent rate than for a short high rate. Any particular battery is given a so-called normal rate. This so-called normal rate is not the capacity obtainable under all conditions. Each different rate of dis-

charge governs the available capacity that may be obtained from the battery.

When discharged continuously at a constant rate, the available ampere-hour capacity of a battery is a function of the rate of discharge, the available capacity being lower at the higher rates, as is shown in Fig. 223. The reduction in available capacity of high-rate continuous discharge is due to depletion of the acid in the pores of the plates. The depletion is due to the fact that at high rates of discharge the acid in the pores of the plates combines with the active material and is withdrawn from the solution more rapidly than it can be replenished by diffusion from the free electrolyte in the cell. It is this limitation of available acid in the pores of the plates that limits the capacity at high continuous rates of discharge, rather than any limitation due to the plates themselves. This explains the fact that, after a battery is exhausted at a high discharge rate, the balance of its normal capacity can be obtained by continuing the discharge at lower rates, or by allowing the battery to recuperate while standing on open circuit for a time and then continuing the high-rate discharge. For this reason also, as stated in Sec. **155,** it is impossible to damage the plates by overdischarge at high rates, as the voltage of the battery will drop below a usable value before the active material in the plates is discharged to the danger point.

Figure 223 shows the available capacity per positive plate of an Exide-Ironclad battery when discharged continuously, in varying lengths of time.

If a battery is discharged intermittently, it is evident that during periods of rest between discharges diffusion will continue, thus renewing the strength of acid in the pores of plates and increasing the available capacity corresponding to the discharge rate. The rate of diffusion depends on the difference in strength of the acid in the pores and that outside the plates, and if this difference is great the diffusion is rapid at first but decreases as they become more nearly equal. It follows from this reasoning that the reduction in available capacity due to high rates of discharge largely disappears when the discharge is intermittent.

If the total elapsed time during which discharges are made is greater than 6 hr., and if the discharges are distributed throughout that time so that there is time for this diffusion to take place, the full 6-hr. capacity of the battery will be available regardless of the rates at which the discharges are taken.

An illustration of the effect of acid diffusion is given in Fig. 224, which shows a test made on a cell of the type used in submarine boats by the U.S. Government.

This cell has a rated capacity of 3,000 amp. for 1 hr. The curve shows it to have been discharged at that rate for 58 min., at which time it was practically exhausted at that rate, and if the discharge had been continued at that rate the voltage would have fallen rapidly. The rate of discharge

was, however, reduced to 1,350 amp. and continued for 45 min.; then to 910 amp. for 30 min.; then to 525 amp. for 1 hr. and 20 min., and finally to 300 amp. for 3 hr. and 15 min. At each reduction in the rate of discharge the rate of acid absorption by the plates was reduced, thus allowing diffusion to strengthen the acid in the pores of the plate and so allowing the discharge to be continued. In each case the voltage at the lower discharge rate was higher than the voltage at the preceding higher rate. During the 300-amp. discharge it will be noted that the voltage continued to rise for over an hour after the start at that rate, showing that the acid from the free electrolyte was entering the pores of the plates faster than it was being absorbed.

The curve showing ampere-hour output shows that 6,000 amp.-hr. was delivered by the cell and that after the battery had been exhausted at

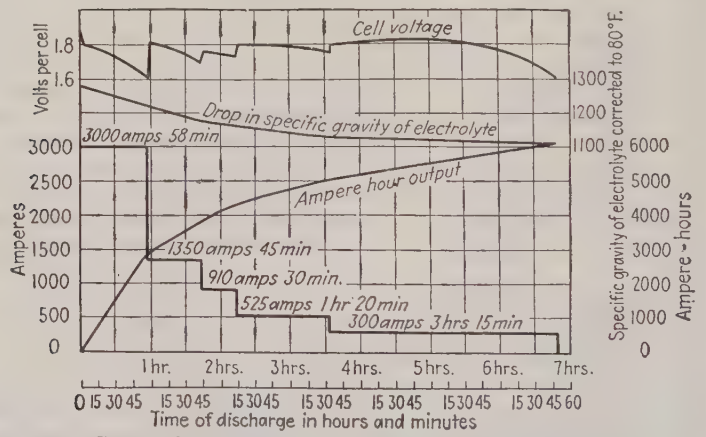


FIG. 224.—Curves showing effect of acid diffusion in lead-acid storage batteries on intermittent discharge. (*The Electric Storage Battery Co.*)

the high rate of discharge as much more energy was still available at lower rates.

158. Discharge Limits of Lead-acid Batteries.—In an emergency, little if any permanent harm will result if the battery is discharged to the full amount that it will give, provided that it is promptly recharged.

It has already been pointed out that the drop in specific gravity of electrolyte should not exceed a certain definite value, which varies according to the type of cell and will be furnished on application to the manufacturer.

The danger of harm from overdischarge may be illustrated by a comparison between the active material of the plates and the action which goes on when some of the electrolyte is allowed to act on copper wiring terminals of a battery. It is noticeable that a comparatively large

amount of copper sulphate is formed when only a small quantity of the metal is eaten away by the acid. In the same manner, when the acid combines with the lead in the active material, the resulting lead sulphate occupies more space than the active material from which it is formed. The active material of all battery plates is porous, and this expansion of the sulphated material is accommodated by reduction in the size of pores in the active material. All battery plates are designed to accommodate a certain amount of this expansion of the active material during sulphation, and in batteries of the type under consideration this is limited to the amount represented by a certain specific-gravity reading.

Further discharge, even if it can be obtained at a satisfactory voltage, results in an excessive expansion, which so closes the pores in the active material that it becomes increasingly difficult to recharge the battery properly after an excessive discharge, and unless a proper recharge is given, the battery is likely to deteriorate.

159. Charging and Charging Rates for Lead-acid Batteries.—A battery must, of course, be charged with direct current, and the current must be connected to the battery so that it will go through it in the proper direction. The positive pole of the charging source must be connected to the positive terminal of the battery, and the negative of charging source to the negative of the battery.

While a battery is being charged, the amount of sulphate in the plates decreases, and the ability of the plate to give up the acid becomes reduced; in other words, during the early part of a charge the plates can give up the acid at a rapid rate, as there is a large amount of sulphate available. Therefore a battery that is considerably discharged can be charged at a high rate, but as the charge approaches completion, currents at high rate cannot be utilized, and if high rates are maintained, only a portion of the current is used to withdraw acid from the plates, and the balance of the current acts to decompose the water in the electrolyte into oxygen and hydrogen, which are given off in the form of gas. Gassing of the battery, therefore, at any time shows whether or not the charging rate is too high. Consequently, when the cells are gassing on charge the rate of charge should be reduced, so as not to waste the current. Furthermore, the action of the bubbles of gas escaping from the pores of the plates and in "boiling" to the top of the electrolyte have a tendency to wash and wear the active material away from the plates, particularly the positive.

It is a well-known fact that batteries wear out. This wear shows itself to the eye principally in the positive plate, the active material of which softens with use, and, were it not for this unavoidable fact, the life of batteries would be very much longer than at present. As the active material of the plate softens with use, there is a tendency for the softened material on the surface of the plate to fall to the bottom of the jar in the form of sediment. The action of the gas in escaping from the pores

of the plates, and the little whirlpools created in the electrolyte when the bubbles of gas boil to the surface, hasten this shedding of material and shorten the life of the battery.

Excessive gassing, therefore, should be avoided if the best life of the battery is to be obtained. A small amount of gassing at low rates and for a short time, at the completion of a charge, is not objectionable, but violent gassing having the appearance of boiling should be avoided.

160. Charging Methods for Lead-acid Batteries.—In practice, charging methods vary with the type of service. For example, in propelling electric vehicles, the battery is discharged over a period of time and then recharged. The rate in amperes to use for recharge depends upon the time available and type of cell. The lower the rate of charge, the longer will be the time required. The shorter the time available, the higher the rate must be to recharge, provided the rate is not higher than recommended for the type of cell. In any event, the rate must always be low at the end of charge when gassing begins. This is known as the finish charge rate.

Batteries charged by this cycle method of discharge and charge can have their charging equipment arranged and designed to provide a taper charge rate automatically and inherently, *i.e.*, high at the start of charge, when a high rate can be utilized, and low at the end of charge when gassing begins. In addition, the equipment can be arranged to stop the charge at the proper time, and all without any manual attention whatever.

Batteries used in starting, lighting, and ignition work on automobiles equipped with a generator for charging are charged whenever the engine is running at ordinary speeds. At very low speeds, or when the engine is not running, the battery supplies current for lights, ignition, and cranking. In automobile service, the rate must be sufficient to keep the battery charged and yet not overcharge it.

Batteries used for reserve emergency, stand-by, or voltage regulation are kept fully charged by a trickle current or floating charge. A constant voltage of appropriate value impressed across the battery terminals is sufficient for proper charging.

Regardless of the charging method, the rate in amperes must not cause excessive gassing, neither should the cell temperature rise above 110°F.

161. Equalizing Charge for Lead-acid Batteries.—Wherever practicable, batteries are given an equalizing charge at regular intervals, for example, weekly for batteries used in propelling vehicles and other services in which the battery is discharged considerably and then recharged; monthly in floating service.

In cycle service an equalizing charge is a continuation of the regular charge at a low rate. In floating service the equalizing charge is obtained by raising the voltage across the battery to increase the current into the battery. The equalizing charge continues until all cells gas freely and

until it is certain by taking voltage and gravity readings that *all* cells are fully charged.

As has already been pointed out, the object of charging is to withdraw all acid from the plates. In practice, the regular charges in cycle service are not always given long enough to completely withdraw all the acid from the plates. In fact, this is not necessary, provided the acid is completely withdrawn regularly by giving an equalizing charge. If this is not done and some sulphate is allowed to remain in the plates for a considerable time, it will gradually increase, and the pores of the plate will become clogged and the battery lose capacity and deteriorate in such a way that it becomes increasingly difficult to restore the battery to its normal condition. To carry frequent (such as daily) regular charges to the full extent would involve an unnecessary amount of charging and gassing which is not desirable.

A battery is not fully charged until all the acid is driven out of the plates by charging. To fully charge a battery, do not try to charge to a fixed or definite gravity, but charge until the specific gravity or voltage stops rising.

162. Effect of Temperatures upon Lead-acid Batteries.—The cell temperature should not exceed 110°F. The effect of high temperature is primarily to shorten the life of the wood separators which are installed between the positive and negative plates of some types of cells.

There is always a tendency for wood in contact with sulphuric acid to become carbonized. This tendency is greatly increased at temperatures above 110°F. If a battery is operated regularly under such conditions it will probably be necessary to renew the wood separators before the battery itself is worn out.

In the materials used in any commercial storage battery, some impurities are also present which cause very slight action in the cell, even when it is not in active operation. At high temperatures, these internal losses are increased, as is evidenced by the fact that a battery placed in storage will not lose its charge seriously over a period of, say, 6 months if kept in a cool place. If kept in a temperature around 100°F., it will lose much more of its charge in, say, 3 months.

Low temperature temporarily decreases both the discharge voltage and the ampere-hour capacity which can be taken out of the battery. The battery acts as if it were numbed by the cold and unable to make the same effort as at normal temperature. The effect of cold is only temporary, the battery returning to its normal state upon its return to normal temperature even without charge. There is no danger of the electrolyte freezing in a fully charged cell, but it is likely to occur in an overdischarged battery or in one that has had the water added without subsequent charging.

163. Types of Lead-acid Storage Batteries.—Lead-acid storage batteries may be roughly divided into three groups depending upon the

class of service for which they are intended. Those for automobile starting, lighting, and ignition work consist of cells assembled in a single

FIG. 225.—Automobile type of lead-acid storage battery. (*The Electric Storage Battery Co.*)

FIG. 226.—Ironclad type of lead-acid storage battery. (*The Electric Storage Battery Co.*)

hard-rubber container (Fig. 225). Those for electric-vehicle applications consist of ironclad-type cells assembled in a suitable container (Fig. 226). Those for stationary service consist of cells enclosed in glass jars (Fig. 227).

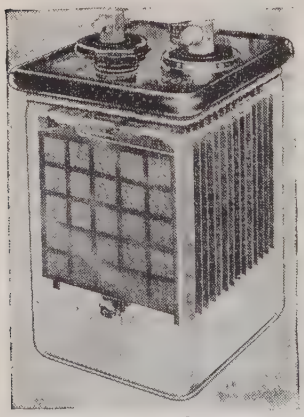


FIG. 227.—Lead-acid storage battery in enclosing glass jar. (*The Electric Storage Battery Co.*)

164. Lead-acid batteries are easily kept in good condition for a long time of trouble-free service if the following maintenance instructions are observed:

1. Keep battery clean outside (Sec. **165**).

2. Add water at regular intervals (Secs. **166** and **167**).

3. Maintain battery in a healthy state of charge (Secs. **169** and **170**).

4. Keep written records (Sec. **171**).

165. Cleanliness.—1. Keep the battery, its connections, and surrounding parts clean and dry by wiping with a dry rag but do not remove the grease from the seal nuts. Keep the vent plugs in place and tight and make sure their gas-escape holes are open. If electrolyte is spilled or if any parts are damp with acid, apply a solution of ammonia or of baking soda (in the proportions of 1 lb. of soda to 1 gal. of water), then rinse with water and dry; do not allow solution to get into cells. If

this treatment is given two or three times a year and the battery kept clean between times by regular washings with water or blowing off with an air jet, the life and service of the battery in general and trays or supports in particular will be increased considerably. Before hosing battery without removing it from compartment consult equipment manufacturer for permission. When washing high-voltage batteries, open the connections at several places to avoid possible shocks.

2. If the terminals or connections show any tendency to corrode, scrape the corroded surface clean, wash it with soda solution or with ammonia solution, rinse with water, and coat it thinly with vaseline or No-Ox-Id grease. No corrosion will occur unless electrolyte is spilled and allowed to remain.

3. Soda solution or ammonia will neutralize the effect of acid on clothing, cement, etc.

166. Adding Water.—1. During operation, water must be regularly added to each cell. Do not allow the surface of the electrolyte to get below the level specified by the manufacturer. Keep it above this point by removing the vent plugs regularly from all the cells and adding sufficient approved water to each cell as often as necessary. Do not fill so high that electrolyte will be lost through the vent plugs, eventually resulting in ruined cells. Less harm will result in allowing the level to get a little low than in adding water too high. After filling be sure to replace and securely tighten the plugs. The intervals at which water must be added depend largely on the operating schedule, but it should not be necessary to add water more often than once a week; otherwise the battery is being given too much charge.

2. In cold weather the time to add water is just before a charge, so that gassing (bubbling of the electrolyte resulting from charging) will ensure thorough mixing, and any danger of the water freezing be avoided.

3. Electrolyte loses some of its water by the charging of the battery and some by evaporation, but its acid is never lost in this manner; therefore, it will not be necessary to add new electrolyte, unless some should get outside the cell through carelessness or by adding too much water so that the container is too full.

4. Nothing but water is required to be added to storage batteries. Never add any special powders, solutions, or jellies. A great many special powder solutions or jellies are injurious, having a corrosive or rotting action on the battery plates, reducing the voltage and capacity of the cells.

5. All the cells in the battery should take the same amount of water. If one cell takes more than the others, examine it for leakage.

6. Keep a written record of the amount of water added from time to time.

167. Kind of Water.—1. The quality of water to add is distilled (not merely boiled) or other approved water. By approved water is meant

that of which the battery manufacturer has analyzed a sample and found safe for their batteries. The local source of water is usually suitable, but before using it the battery manufacturer should be consulted. Most companies will do this without charge for users of their batteries. Transportation charges should be prepaid and the sample marked for identification.

2. If water is drawn from a tap or spigot it should be allowed to run a few moments before it is used, to remove pipe accumulations. Water should not be transported or stored in any metallic vessel except lead. Glass, earthenware, rubber, or wooden receptacles that have not been used for any other purpose are satisfactory.

168. Discharge Limits.—1. In an emergency, little if any permanent harm will result if the battery is discharged to the full amount that it will give, provided that it is promptly and fully recharged.

2. If an ampere-hour meter is in use, the discharge should be stopped and the battery promptly recharged before or upon reaching its capacity limit in ampere-hours, as given by the manufacturers. The ampere-hour

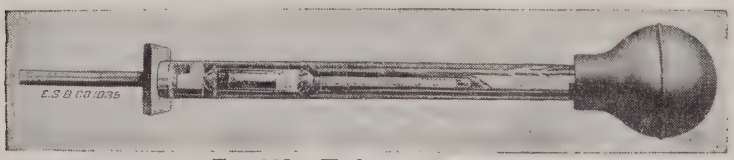


FIG. 228.—Hydrometer syringe.

meter will run slow if the discharge is at high rates or if the meter is not calibrated at proper intervals and will then show less discharge than the battery actually gives. This fact should not be overlooked.

3. The specific gravity of the electrolyte falls on discharge and is therefore an indication of the amount of discharge. The difference between the full-charge and discharge values of the gravity depends on the type of cell. The manufacturer of the battery should be consulted for the proper values for any particular cell.

169. Hydrometer Readings—Specific Gravity.—1. If the specific-gravity or hydrometer reading is known, one can tell if the battery is fully charged or the amount it is discharged. With all cells connected in series, the gravity reading of one cell, known as a pilot cell, will indicate the state of discharge or charge of the whole battery.

2. The specific gravity is easily determined by allowing a hydrometer to float in the electrolyte. When the specific gravity is high, the hydrometer will not sink so far into the electrolyte as when the specific gravity is low (see Fig. 219).

3. To take a reading, insert the nozzle of the hydrometer syringe (Fig. 228) into the cell, squeeze the bulb, and then slowly release it, drawing up just enough electrolyte from the cell to float the hydrometer freely.

With the syringe held vertically, the reading on the stem of the hydrometer at the surface of the liquid is the gravity reading of the electrolyte. After testing, always return the electrolyte to the cell from which it was taken.

4. Both temperature and level of electrolyte affect the specific gravity reading somewhat, and it is therefore desirable to record the temperature and level of the electrolyte at the same time its gravity reading is taken. A gravity reading should not be taken immediately after adding water, as the reading will give a false indication of the specific gravity. Allow a day or so for the water to mix with the electrolyte by gassing (bubbling) of the electrolyte resulting from charging or floating the battery.

5. After every fifty-odd gravity readings of a pilot cell, a different cell should be used as a pilot, in order to avoid lowering of its gravity due to possible loss of a small amount of electrolyte each time the gravity is read.

6. Hydrometer syringes are available for mounting through the vent plug of a pilot cell (Fig. 229). Since they are continuously in place, no dripping is experienced and the pilot cell need not be changed after every fifty-odd readings.

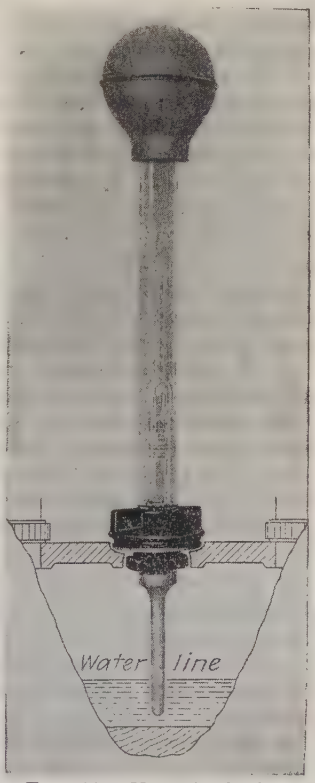


FIG. 229.—Vent plug hydrometer syringe (scale 1.100 to 1.300) mounted in pilot cell. (*Electric Storage Battery Co.*)

170. Full-charge Specific Gravity.—1. The proper specific gravity of the electrolyte with the cells fully charged and with the electrolyte at the proper level, as specified by the maker, will vary somewhat with different types of batteries. The manufacturer should be consulted for the proper value.

2. The specific gravity of a new battery is adjusted at the factory and will not require adjusting during the life of the battery, unless electrolyte is actually lost out of the battery. If, however, electrolyte is lost it should be replaced with electrolyte of about the same specific gravity as is in the surrounding cells.

3. The full-charge specific gravity will decrease in value as the battery ages. No definite value can be given, but this decrease is very small, not

over a few points per year at the most. This change is mentioned so that it will be understood.

4. Before adjusting low gravity, first make sure charging will not raise gravity. To do this, continue an equalizing charge until specific gravity shows no rise, and then for 3 hr. more. Never make a gravity adjustment on a cell which does not gas on charge.

5. To adjust low gravity, first have ready sulphuric acid of specific gravity between 1.265 and 1.300, sufficiently pure for storage-battery use. Add this instead of water when restoring level until the gravity at the end of an equalizing charge is normal. Then stop adding acid and return to the use of water. A quicker method, but one requiring more work and acid, is to withdraw some of the low-gravity electrolyte from the cell and at once replace it with this new electrolyte. Do not allow a cell to stand partly empty. The amount to withdraw will have to be determined by trial, as it depends upon the gravities of both the old and new electrolyte. Charge until all cells have been gassing for 1 hr. Then, if the gravity is not normal, repeat adjustment until it is.

6. To adjust high gravity, remove some of the electrolyte and replace with water until the gravity at the end of an equalizing charge is normal.

171. Readings—Written Records.—1. To facilitate following the operation of the battery, it is advisable to record the specific gravity and voltage of each cell at intervals. The relative state of charge should be the same each time readings for record are taken—for instance, on a manually cycled battery, at the end of a charge; on a floated battery, 10 to 15 min. after starting the monthly equalizing charge.

2. Cell voltage readings should be taken while the charging current is being maintained and not after it is reduced or interrupted. During these readings the battery voltage or the charging current into the battery should be kept constant. Cell gravities should be taken 10 or 15 min. after charge is completed and not while cells are gassing heavily.

3. The individual cell voltages, read to the hundredth of a volt, should be recorded once a month, in which case three or four times a year will be sufficient for recording the cell gravities. Otherwise cell gravities should be recorded monthly.

4. Review the monthly cell readings and compare with those for the previous month promptly. Plotting the readings saves time in reviewing and comparing. Prompt action upon indication of trouble may save time and expense later (see Sec. **172**).

172. Trouble.—1. The chief indications of trouble in a cell are:

Falling off in gravity or voltage relative to the rest of the cells.
Lack of gassing on equalizing charge.

2. If a battery seems to be in trouble, the first thing to do is to give it an equalizing charge (Sec. **161**). Then take a gravity reading of each cell. If all the cells gas evenly on the equalizing charge and the gravity

of them all goes above a certain value as specified by the manufacturer, then all the battery needed was the charge. Before making an adjustment, determine whether the jar is cracked by adding water to the proper height and allowing cell or jar to stand several hours, noting whether level falls. If a jar is cracked change it. Never make a gravity adjustment on a cell which does not gas. If a cell will not gas on the equalizing charging, investigate for impurities or inspect it for short circuits. For the latter, remove the elements from the jar and examine the separators carefully to make sure that none is broken or damaged, thus causing a short circuit. Also examine plates to see that they are in good condition and note the height of sediment in the bottom of the jar. Remove any collection of "moss" on the top or edges of the plates. Handle elements very carefully, so that plates will not be broken from the straps. Replace damaged separators.

173. Impurities.—Impurities in the electrolyte will cause a cell to work irregularly. Should it be known that any impurity has got into a cell, it should be removed at once. In case removal is delayed and any considerable amount of foreign matter becomes dissolved in the electrolyte, this solution should be replaced with new immediately, thoroughly flushing the cell with water before putting in the new electrolyte. If in doubt as to whether the electrolyte contains impurities, a sample should be submitted for test.

174. Sediment.—The sediment which collects underneath the plates need cause no alarm unless it deposits too rapidly, in which case there is something wrong with the way the battery is operated. In a new battery there is always a thin layer at the start. As the battery wears, the sediment becomes higher, but, for batteries which are floated, the plates usually wear out before the sediment space is filled.

175. Putting Battery into Storage.—1. If the use of the battery is to be temporarily discontinued, give it a charge until all the cells gas and add water to the cells during this charge so that the gassing will ensure thorough mixing and prevent its freezing in cold weather. Add enough water to raise the level of the electrolyte to the proper level. After the charge is completed, remove all fuses to prevent the use of the battery during the idle period. Make sure all vent plugs are in place.

2. At certain periods the battery should be reconnected, water added, and the battery charged. These periods are every 2 months in climates averaging 70 to 80°F. and every 6 months in climates averaging 40°F.

176. Putting Battery into Commission Again.—Add water, if needed, and give a charge until the gravity of the electrolyte has ceased rising over a period of 3 hr.

NICKEL-IRON-ALKALINE BATTERIES

177. The Edison storage battery is the result of an effort to avoid many of the disadvantages of the lead-sulphuric acid combination and is a radical departure therefrom in every detail of construction. The positive

plate consists of hollow, perforated, sheet-steel tubes filled with alternate layers of nickel hydrate and metallic nickel. The hydrate is the active material and the metal, which is made in the form of microscopically thin flakes, is added to provide good conductivity between the walls

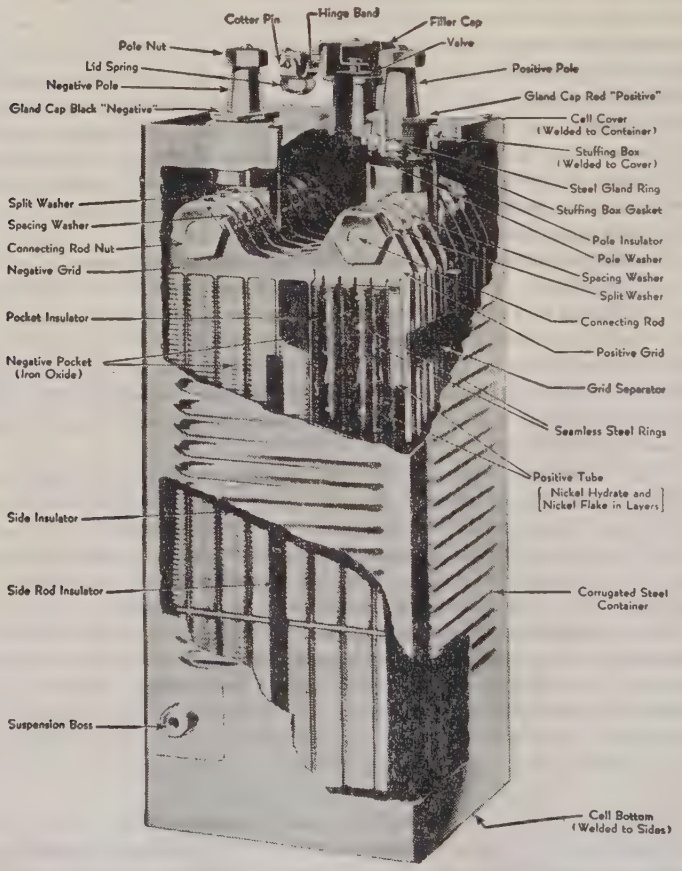


FIG. 230.—Edison nickel-iron-alkaline storage cell with container cut away to show construction detail. (*Edison Storage Battery Co.*)

of the tube and the remotest active material. The negative plate is made up of perforated, flat, sheet-steel boxes or pockets loaded with iron oxide and a small amount of mercury oxide, the latter also for the sake of conductivity. The grids which support these tubes and pockets are punchings of sheet steel. The cell terminals and container are likewise of steel, and all metallic parts are heavily nickel-plated. The electrolyte

is a 21 per cent solution of caustic potash containing also a small amount of lithium hydrate. All separators and insulating parts are made of rubber. The details of construction are shown in Fig. 230.

The current used in charging causes an oxidation of the positive plate and a reduction of the negative, and these operations on discharge are reversed. The electrolyte acts merely as a medium and does not enter into combination with any of the active material as it does in the acid battery. Its specific gravity remains practically constant throughout the complete cycle of charge and discharge. The charge and discharge curves are shown in Fig. 231.

The chief characteristics of the battery are ruggedness, due to its solid, steel construction; low weight, due to its stronger and lighter supporting metal; long life, due to the complete reversibility of the chemical reactions

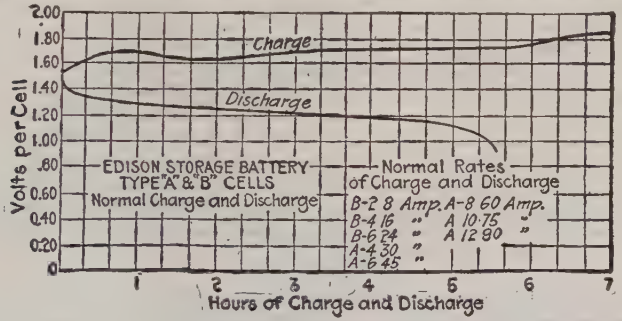


FIG. 231.—Charge and discharge curves of the Edison battery.

and the absence of shedding active material; and low cost of maintenance, due to its freedom from the diseases, such as sulphation, so commonly met with in storage-battery practice, and from the necessity of internal cleaning and plate renewals. The arguments against it are high first cost and high internal resistance. The importance of these must, of course, be weighed with the advantages and the resultant considered in each proposed installation. The battery has attained its chief prominence in vehicle propulsion, but its characteristics also recommend it for many other purposes.

178. Voltage Characteristics.—The voltage of each cell is approximately 1.5 volts on open circuit, but is higher than this when the battery is being charged and lower when being discharged. The voltage at any time depends upon state of charge or discharge, the temperature, and the density of the electrolyte. The average discharge voltage is approximately 1.2 volts per cell. Typical voltage charge and discharge curves are shown in Fig. 231. Cells are generally discharged until the voltage drops from 1.0 to 0.9 volt per cell. Further discharge is generally not satisfactory since the voltage drops very rapidly if the discharge is continued past this point. The maximum voltage during charge will be

between 1.80 to 1.90 volts per cell. The voltage for any degree of discharge is affected slightly by the rate of discharge, as shown in Fig. 232.

179. Rating of Nickel-iron-alkaline Batteries.—All batteries are given a normal ampere-hour capacity rating based on a certain rate of discharge to a final voltage of 1.0 volt per cell. Some current ratings are based on a 5-hr. continuous discharge rate and others on a 3⅓-hr. continuous rate.

The ampere-hour capacity for discharging continuously at a constant rate to a final voltage of 1.0 volt per cell will be affected by the rate of discharge (Fig. 232). The higher the rate of discharge the lower is the capacity of the battery. The effect upon the capacity will not be so great, however, as it is for lead-acid batteries. After a high rate of

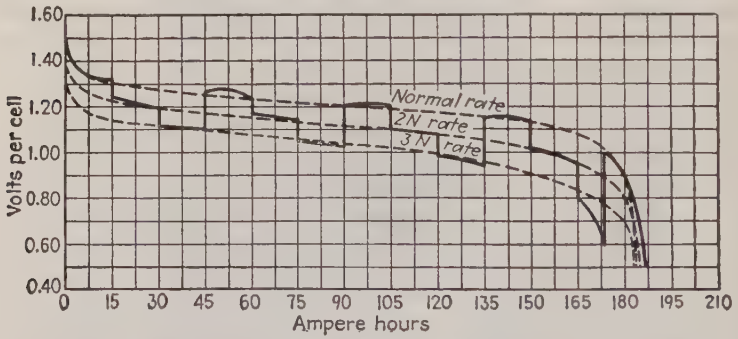


FIG. 232.—Discharging at high rates. A4 cell, normal rate 30 amp., discharged successively at 30, 60, and 90 amp. with comparison of continuous discharge at each of these rates. (*Edison Storage Battery Co.*)

discharge, the balance of the normal capacity of the battery can be obtained by continuing the discharge at a lower rate. If the battery is discharged intermittently, the normal capacity can be obtained unless the total elapsed time of discharge is excessively short. These batteries are very rugged and withstand very severe service. They are not harmed by occasional short-circuit discharges.

180. Charging.—The best method of charging Edison batteries is by the average-constant-current method. The battery is connected in series with an adjustable resistance to a constant-potential, d-c supply, as shown in Fig. 233. The positive terminal of the battery should be connected to the positive terminal of the supply. The maximum voltage available at the batteries should be at least 1.85 times the number of cells in series. Throughout the charging period the rheostat should be periodically adjusted so that the average current will be maintained at its normal rated value. At each adjustment the current should be set a few amperes above the rated value so that by the time the next adjustment is made the current will not have dropped much below normal. The battery should be charged until a maximum voltage has been reached and maintained for 30 min. If an ampere-hour meter is used with the

battery in charge and discharge, satisfactory charge is generally obtained by charging the battery at its rated current until the ampere hours of charge is 125 per cent of the ampere-hours of discharge. The condition of charge cannot be judged by means of specific-gravity readings. Automatic equipment for the control of the current during charge is being used to a greater and greater extent.

Before starting to charge, see that the solution is at the proper level. If the solution is low, bring it to the proper level by adding pure distilled water as instructed under watering. If the battery is in a compartment, open the covers before starting a charge. If necessary, and if full capacity is not required, a battery may be taken off charge at any time and used.

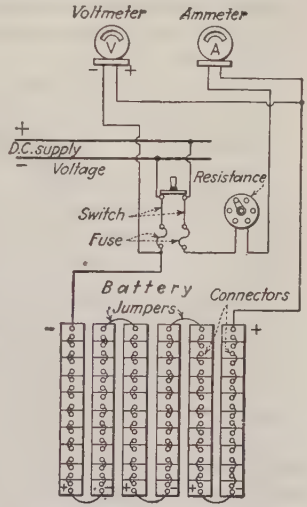


FIG. 233.—Showing correct connections for charging a battery at constant current through a variable resistance. (*Edison Storage Battery Co.*)

181. Effect of Temperature.—Do not charge in a hot place or allow the temperature of the solution to exceed 115°F. on charge. High temperatures during charge or discharge will shorten the life of any kind of battery. Better efficiency is obtained if cells are charged at a temperature of 80 to 90°F. If the temperature of the solution exceeds 115°F. while charging, allow the cells to cool before continuing the charge.

182. Charging at High Rates.—In an emergency, when time for a normal charge is not available, charging may be done at any higher rates than normal, provided there is no frothing and the temperature does not rise above 115°F.

183. Charging at Low Rates.—Where the discharge requirements are such that a low constant rate is used or where an intermittent rate of such value that for a given time period a low average rate will be had, then a charge rate of less than normal may be used, provided that this charge rate is approximately 120 per cent of the constant or average discharge rate. The term low discharge rate is to be construed to mean a constant or average rate of less than 80 per cent of normal.

When charging at low rates it must be thoroughly understood that the required ampere-hour input must be put in, and that, therefore, the time periods of charge must be correspondingly increased over that necessary to fully charge a cell at normal rate.

184. Boosting Charge.—An Edison battery may be boosted, *i.e.*, given a supplementary charge, at high rates during brief periods of idleness thereby materially adding to the available capacity. The principal

limiting feature is that the temperature of the solution in the cells nearest the center or the warmest part of the battery does not exceed 115°F. A battery can be boosted whether it is entirely discharged or only partially discharged. The object of the boost is to supplement the remaining charge so that additional work may be done without waiting for regular charge.

The following table gives figures that may be used under average conditions, but values that will not cause excessive heating must be determined in each case by experience:

5 minutes at five times normal.
15 minutes at four times normal.
30 minutes at three times normal.
60 minutes at two times normal.

Frothing at the filler opening is an indication that the boosting has been carried too far (if the solution is at the proper height), and the boosting should be discontinued at once.

185. Overcharging is to be interpreted as charging a battery at the normal rate for periods in excess of the specified Hours Normal Charge. For A, B, C, and N Types, 12 hr. is considered an overcharge when the previous discharge has only been taken to an average of approximately 0.5 volt per cell, and 15 hr. is considered an overcharge when the previous discharge has been taken to zero voltage and short-circuited. For G and L Types these overcharge periods are, respectively, 8 and 10 hr.

Overcharging in conjunction with proper discharges is used to compensate for either lack of work of battery or change of solution. In those cases where batteries have become sluggish due to lack of work, such as where batteries are seldom totally discharged in regular service, the battery should be periodically completely discharged to zero at normal rate and then short-circuited for 1 or 2 hr. Follow with a regular overcharge.

With new Edison batteries better capacities will result if they are given plenty of work. It is, therefore, advisable to give new batteries additional work every 2 weeks for the first 2 months and every 2 months thereafter for 6 months. This should consist of a complete discharge to zero at normal rate with a short circuit of at least 2 hr. followed by an overcharge.

When an Edison battery does not give satisfactory capacity on discharge at rates several times normal it is considered sluggish. This sluggishness or low capacity may result from persistent low-rate discharging, frequent low-rate charging, long stands, seldom discharging completely, or weak solution. With the exception of the last named the primary cause is lack of work. Edison batteries thrive on work; therefore, the proper procedure is to discharge the battery completely at normal rate to zero and then short-circuit it for 2 hr. Follow this by a overcharge. If the condition is rather pronounced the cycle should be repeated. In

the worst cases results can usually be obtained by several repetitions of the above. Ordinarily, this method will restore underworked batteries.

Completely discharge batteries before starting overcharges. Test for height of solution and bring the solution to the proper height. Tests of solution height should be made before and after the battery is completely discharged at normal rate, followed by a short circuit of at least 2 hr. and then an overcharge.

186. Data for Nickel-iron-alkaline Batteries
(Edison Storage Battery Co.)

Cell type	Rating[a]		Weight,[b] lb. per cell	
	Ampere-hour capacity	Normal rate, amp.	Standard	High type
N2	11¼	2¼	1.94	
L20	12½	3¾	1.88	
L30	18¾	5⅝	2.64	
L40	25	7½	3.24	
B1, B1 *H*[c]	18¾	3¾	5.3	6.7
B2, B2 *H*[c]	37½	7½	6.0	7.2
B4, B4 *H*[c]	75	15	9.5	10.9
B6, B6 *H*[c]	112½	22½	13.0	15.2
A4, A4 *H*[c]	150	30	16.5	19.3
A5, A5 *H*[c]	188	37½	19.6	22.5
A6, A6 *H*[c]	225	45	22.4	25.5
A7, A7 *H*[c]	263	52½	25.8	28.6
A8, A8 *H*[c]	300	60	31.2	35.9
A10, A10 *H*[c]	375	75	38.1	43.8
A12, A12 *H*[c]	450	90	47.3	53.5
A14, A14 *H*[c]	525	105	56.6	60.8
A16, A16 *H*[c]	600	120	62.9	68.0
A20 *H*[c]	750	150	....	84.8
A24 *H*[c]	900	180	....	102.5
G4, G4 *H*[c]	100	30	12.5	19.0
G6, G6 *H*[c]	150	45	17.5	21.1
G7, G7 *H*[c]	175	52½	20.8	23.0
G9, G9 *H*[c]	225	67½	24.0	27.5
G11, G11 *H*	275	82½	30.4	36.2
G14, G14 *H*	350	105	37.2	44.5
G18, G18 *H*	450	135	52.4	56.8
G22 *H*[c]	550	165	....	70.0
C4	225	45	24.3	
C5	281	56¼	29.3	
C6	338	67½	34.4	
C7	394	78¾	39.8	
C8	450	90	45.5	
C10	563	112½	61.3	
C12	675	135	71.0	
D6	450	90	45.6	
D8	600	120	60.0	
D10	750	150	77.3	
D12	900	180	91.6	

[a] Ratings are on basis of 5-hr. rate for A, B, C, and N Type cells and 3½-hr. rate for G and L Type, with average of 1.2 volts per cell and final of 1.0 volt per cell.

[b] Weights are for completely assembled cells, including trays, connectors, etc.

[c] The letter *H* indicates high-type cells; these cells have the same characteristics as the standard-type cells but are built higher so as to hold more electrolyte and are used in installations where frequent flushing is not convenient.

187. Maintenance of Nickel-iron-alkaline Batteries.—The attention required by this battery is of the simplest character. It is chiefly important that the electrolyte be replenished from time to time with distilled water so that the plates will be entirely immersed, and that the outside of the cells be kept clean and dry, for, if this is not done, leakage of current will occur with consequent corrosion of containers by electrolysis. Perhaps once or twice during the total useful life of the cell, the electrolyte may need renewal.

188. Cleaning.—The cells, trays, and battery compartment must be kept dry, and care must be taken that dirt and other foreign substances do not collect at the bottom or between the cells.

Dirt and dampness are likely to cause current leakage, which may result in serious injury to the cells.

Where protection of cell tops from moisture is required, they should be given a light coat of Rosin or Liquid Esbaline, this material being applied to the cover of the cell and sparingly to the outside of the filling aperture, care being taken not to get any great quantity on the lid hinge. Esbaline may be applied best with a small paintbrush, care being taken not to get any on the inside of lugs or on cell poles.

Rosin Esbaline must be applied warmed to approximately 170 to 190°F. and thinned to good paint consistency with benzine, etc.

A wet steam jet, or even an air blast, will be found most satisfactory for cleaning but must not be used on cells while they are in the compartments. It has been found that a pressure of 70 lb. with a 1-in. rubber steam hose about 10 ft. long into which has been inserted a piece of iron pipe about 12 in. long with an orifice $\frac{1}{8}$ in. in diameter will give wet steam with a velocity to clean the battery satisfactorily. (This orifice can be made by plugging one end of an iron pipe and drilling out with a $\frac{1}{8}$-in. drill.) When removing encrustations from the tops of cells, do not allow them to fall between or into the cells. Before reassembling, make sure that all poles, connectors, and jumper lugs are clean. Also cells, trays, and compartments must be dry before the battery is replaced.

Occasionally, cells and trays after being cleaned should be recoated with Esbalite, an alkali-proof insulating paint put up by the Edison Storage Battery Division of Thomas A. Edison, Inc.

The cells should be thoroughly cleaned of all grease, dirt, dried salts, and paint blisters or flakes and be perfectly free from all moisture. Painting may be done with a brush or, if the quantity is large, by dipping.

When cleaning and recoating with any cell coating, be careful not to allow any of the materials to get into the cells.

189. Water or Flushing.—Do not allow the level of the solution to drop below the tops of the plates. Never fill higher than the proper level. If filled too high, solution will be forced out during charge.

For replenishing solution in Edison cells during operation use only pure distilled water or water which has been tested and approved by the

Edison Storage Battery Division of Thomas A. Edison, Inc. Although pure distilled water is recommended for use in storage batteries generally, there are certain points in the country where the local water supply is of such purity that it may be satisfactorily used. It is extremely important that no other water than pure distilled water be used unless it has received the approval of the Edison Storage Battery Division of Thomas A. Edison, Inc., after test at the factory's laboratories. The use of impure water will result in a slow poisoning of the electrolyte by an accumulation of impurities, the effect of which may not appear within a few months but will ultimately become apparent within the course of several years.

When solution has been spilled, use standard refill solution, which has a specific gravity of approximately 1.215 at 60°F.

Battery compartments and trays must be kept dry and clean at all times, so take care, when filling cells, not to spill water over and around the cells and not to exceed specified height.

Test for height of solution before placing battery on charge. Do not test for solution height while battery is charging; the gassing during charge creates a false level.

A reasonably heavy-walled glass tube about 8 in. long and of not less than $\frac{3}{16}$ in. inside diameter with ends cut straight and fused enough to round the edges may be used as illustrated in Fig. 234 to find level of electrolyte above plate tops. A short length of tightly fitting rubber tube forced over one end and projecting about $\frac{1}{8}$ in. will prove a very good finger grip. Insert the tube until the tops of the plates are touched; close the upper end with the finger and withdraw the tube. The height of the liquid in the tube should be as specified in Electrical Data.

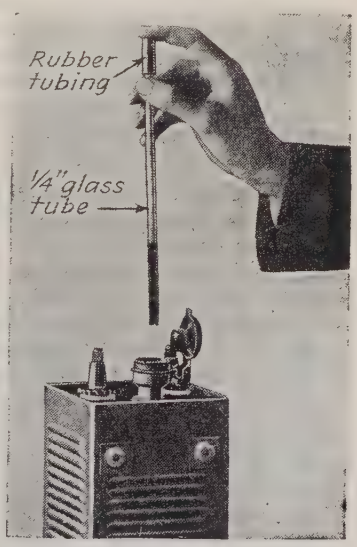


FIG. 234.—Quick method of determining height of solution. (*Edison Storage Battery Co.*)

190. Specific Gravity of Nickel-iron-alkaline Batteries.—The density or specific-gravity reading of the electrolyte of an Edison cell has no value in determining the state of charge or discharge, as the specific gravity does not change during the charging or discharging of the cell to any marked extent. The small changes ordinarily observed are due either to large changes in temperature or to loss of water from the electrolyte by evaporation or electrolysis in operating the cell. Therefore it is not

necessary to take frequent readings to determine the specific gravity. The only time it is necessary to obtain specific-gravity reading is to determine when a change of electrolyte would be advantageous. When making these readings, certain fundamental conditions must be observed. A suitable hydrometer must be obtained and used in accordance with the rules laid down in the section headed Use of Hydrometer. The glass container must be clean and must not contain acid or other impurities as these tend to give lower readings than the true specific gravity.

Do not take specific-gravity reading when the cell is charging, as the bubbles of gas contained in the electrolyte will cause a lower reading than the true one. Readings taken when the temperature of the electrolyte is either very high or very low will give results that will vary with the temperature. The specific gravities quoted in this section are for 60°F. Temperatures very much higher than this will give lower gravity readings, while temperatures very much lower than this will give higher readings.

Specific-gravity readings taken immediately after watering the cell are of no value, as the water has had no chance to be thoroughly mixed with the electrolyte, and the resulting readings will be low. The specific gravity should be taken when the electrolyte is at the proper height after a complete charge. It is best to allow the cells to stand for a short period after the completion of the charge to allow free bubbles of gas to dissipate before taking readings. Corrections for temperature should be made by adding 0.0025 for each 10 degrees above 60°F. to the observed reading or subtracting 0.0025 for every 10 degrees below 60°F.

After taking a specific-gravity reading, return the solution to the same cell from which it was taken. Otherwise the gravity of the solution in the cell to which it is added will be increased, and the gravity of the solution in the cell it is taken from will be decreased, owing to the addition of water made necessary.

The potash electrolyte in Edison cells has a normal specific gravity of approximately 1.200 at 60°F. when at the normal level and thoroughly mixed by charging and when sample is taken at least ½ hr. after charge, to allow for dissipation of gas.

191. Solution Renewal.—Throughout the total useful life of the cell the electrolyte gradually weakens and may need renewal once or twice, depending on the severity of service, and in some cases, where maintenance and operation have been poor or where contamination has been allowed by the use of impure water, etc., a third time might be necessary.

The low-limit specific gravity beyond which it is inadvisable to run an electrolyte is 1.160. Operation at lower specific gravity than 1.160 should not be allowed since such operation will produce sluggishness, loss of capacity, and rapid breakdown on severe service. Should the specific gravity be above 1.160 and at the same time sluggishness and loss of capacity be evident, do not immediately renew the electrolyte until it is found that an electrolyte sample sent to the factory shows a prohibitive

accumulation of impurities and until the following treatment fails to produce marked improvement.

1. Discharge at normal rate to zero voltage. (When the current can no longer be kept up, either reverse the battery on the line with sufficient resistance in series or connect in series with another more nearly charged battery; then continue the discharge.) It is of prime importance that the rate be kept at normal throughout.

2. Short-circuit the battery in groups of not more than about 5 cells each for at least 2 hr.

3. Charge at normal rate for 15 hr. for A, B, C, and N Types and 10 hr. for G and L Types.

4. Discharge at normal rate to approximately 1.0 to 0.9 volt per cell.

5. Charge at normal rate for 7 hr. for A, B, C, and N Types and 4¾ hr. for G and L Types.

6. Discharge at normal rate to approximately 1.0 to 0.9 volt per cell.

If the cells do not respond noticeably to this treatment there is probably very marked contamination of the electrolyte, and the result of the analysis of a representative sample sent to the factory at West Orange, N.J., in accordance with the section Analysis Samples of Water and Electrolyte, will show this. Therefore, regardless of the specific gravity, the electrolyte should be replaced as follows:

1. When previous electrolyte has reached approximately the low limit of 1.160, the new solution should be Standard Renewal.

2. When previous electrolyte is 1.190, or above, the new solution should be Standard Refill.

It is always advisable, in case the battery exhibits trouble of any sort, to communicate all details to the Edison Storage Battery Division of Thomas A. Edison, Inc., West Orange, N.J., attention of the Service Dept., so that immediate advice may be obtained.

Do not use any other solution than Edison Electrolyte. Do not pour out old solution until you have received new and are ready to use it. Never allow cells to stand empty. State type and number of cells when ordering Edison Electrolyte for renewal.

When ready to renew solution, first completely discharge the battery at normal rate to zero and short-circuit for 2 hr. or more. This is to protect the elements. Then empty cells completely. It is not necessary to shake or rinse cells, and under no circumstances should cells be filled with water.

Immediately after emptying each cell pour in new solution. Do not allow to stand empty. Fill to exactly the proper height. For this purpose use a clean glass or enamelware funnel. A plain iron funnel can be used if it has no soldered seams, but do not by any means use one of tinned or galvanized iron. A clean rubber tube may be used to siphon the solution directly from the container to the cell. If the tube is new it should be thoroughly soaked in electrolyte for a couple of hours or filled

with electrolyte and allowed to stand a couple of hours in such a position as to retain the solution. This is to remove thoroughly any impurities on the rubber. Fill to exactly the proper height, for if cells are filled too full when renewing the solution and allowed to remain that way the specific gravity of the electrolyte will be too high when the level of the solution returns to proper height. This condition may lead to serious results and can easily be avoided by reasonable care.

Do not attempt to put in all solution received as an excess is allowed to make up for any loss due to spilling. It may be necessary to add some more electrolyte after cells have stood a little time, as some electrolyte may be absorbed by the plates.

The specific gravity of the Edison Electrolyte for renewal as shipped is about 1.250, but this will quickly fall to normal when put into a battery, owing to mixture with the old, weak solution remaining in the plates.

Do not attempt to use the Electric Filler for refilling cells. It was not designed for this purpose and will not work.

When the new electrolyte is in and the battery is again connected for service, give it an overcharge at the normal rate as outlined under Overcharging.

192. Cautions in Operation of Nickel-iron-alkaline Batteries.—1. Never put lead-battery acid into an Edison battery or use utensils that have been used with acid; you may ruin the battery.

2. Never bring a lighted match or other open flame near a battery.

3. Never lay a tool or any piece of metal on a battery.

4. Always keep the filler caps closed except when necessary to have them open for filling.

5. Keep batteries clean and dry externally.

6. Edison electrolyte is injurious to the skin or clothing and must be handled carefully. Solution spilled on the person should be immediately washed away with plenty of water.

193. Laying up Nickel-iron-alkaline Batteries.—If battery is to be laid up for any length of time be sure that the plates are covered to the proper height by solution or electrolyte. The battery should be stored in a dry place. Do not leave it in a damp place, as damage to the containers may result from electrolysis. Never let the battery stand unfilled.

Edison batteries are easy to lay up. Merely discharge to zero voltage and short-circuit. They may be left standing idle indefinitely in this condition without injury.

New Edison cells have received sufficient cycles of charge and discharge before shipment to give considerable capacity above rated. However, Edison cells will increase still further in capacity if thoroughly worked in. Therefore it is best, if new cells are to stand for some time before being put into commission, to discharge them to zero at normal rate and short-circuit at least 6 hr.

When putting the battery back into commission, go over each cell and

see that all poles and connections are in good condition as for a new cell. See that the plates are properly covered with electrolyte and then charged as here instructed: First, if not already discharged, discharge cells to zero at normal rate and short-circuit. Follow this by an overcharge at normal rate and then discharge at normal rate. Then charge at normal rate for normal hours of charge. If the battery shows signs of sluggishness, repeat the overcharge and carry the discharge down to zero until cells are fully active; then give regular charge.

INSTALLATION OF STORAGE BATTERIES

194. In installing storage batteries, follow the rules of the National Electrical Code, which are given below:

195. Scope.—The provisions of this section shall apply to all stationary installations of storage batteries using acid or alkali as the electrolyte and consisting of a number of cells connected in series with a nominal voltage in excess of 16 volts.

196. Definition of Nominal Voltage. The nominal battery voltage shall be calculated on the basis of 2.0 volts per cell for the lead-acid type, and 1.2 volts per cell for the alkali type.

197. Wiring and Apparatus Supplied from Batteries.—Wiring, appliances, and apparatus supplied from storage batteries shall be subject to the requirements of the Code applying to wiring, appliances, and apparatus operating at the same voltage, except as otherwise provided for communication systems in Art. 800 of the National Electrical Code.

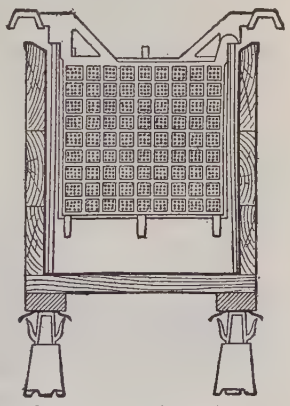


FIG. 235.—A cell in a lead-lined wood tank, supported on oil insulators.

198. Insulation of Batteries of Not Over 250 Volts.—The provisions of this section shall apply to storage batteries having the cells so connected as to operate at a nominal battery voltage not exceeding 250 volts.

1. **Lead-acid Batteries.**—Cells in lead-lined wood tanks, where the number of cells in series does not exceed 25, shall be supported individually on glass or glazed-porcelain insulators (see Fig. 235). If the number of the cells in series exceeds 25, the cells shall be supported individually on oil insulators.

2. **Alkali-type Batteries.**—Cells of the alkali type in jars made of conducting material shall be installed in trays of nonconducting material, with not over 20 cells in a series circuit in any one such tray, or the cells may be supported singly or in groups on porcelain or other suitable insulators (see Fig. 236).

3. **Unsealed Jars.**—Cells in unsealed jars made of nonconductive material shall be assembled in trays of glass or supported on glass or

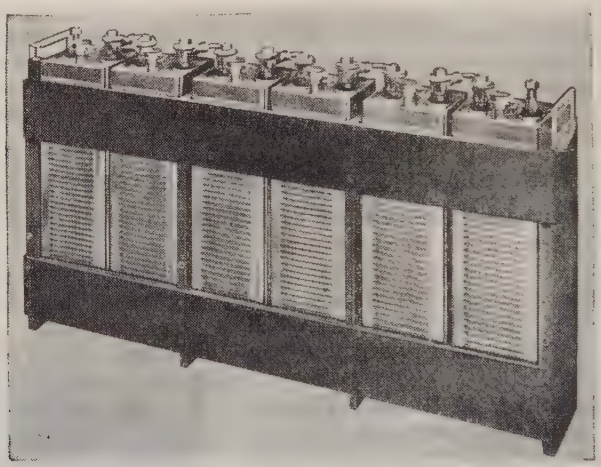


FIG. 236.—Alkali-type battery with cells mounted in an insulating tray. (*Edison Storage Battery Co.*)

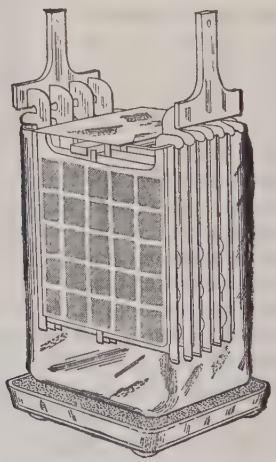


FIG. 237.—A cell in an unsealed glass jar, mounted on a sand tray.

glazed-porcelain insulators, or, if installed on a rack, shall be supported singly or in groups on glass or other suitable insulators (see Fig. 237).

4. **Sealed Rubber Jars.**—Cells in sealed rubber or composition containers shall require no additional insulating support if the total nominal

voltage of all cells in series does not exceed 150 volts. If the total voltage exceeds 150 volts, batteries shall be sectionalized into groups of 150 volts or less and each group shall have the individual cells installed in trays or on racks. If trays or racks are required for this type of cell, such trays or racks shall be supported on glass or glazed-porcelain insulators or oil-type insulators.

5. **Sealed Glass Jars.**—Cells in sealed glass jars, with or without wood trays, require no additional insulation.

199. Insulation of Batteries of Over 250 Volts.—The provisions of Sec. **198** shall apply to storage batteries having the cells so connected as to operate at a nominal voltage exceeding 250 volts and, in addition, the provisions of this section shall also apply to such batteries.

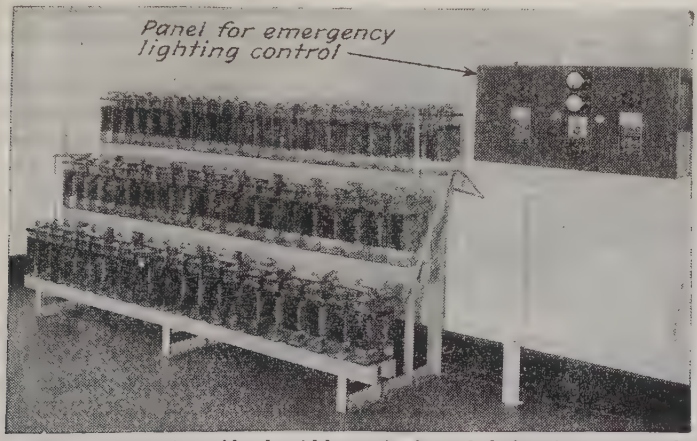


FIG. 238.—Installation of lead-acid batteries in sealed glass jars mounted on a three-tier rack for emergency lighting. (*The Electric Storage Battery Co.*)

1. Cells shall be installed in groups having a total nominal voltage of not over 250 volts, in trays or on racks supported on oil insulators, except that, if each individual cell, or subgroup in the tray or rack, is supported on oil insulators, no additional insulation for the group need be provided, and except that cells of not over 10-ampere-hour capacity in sealed glass jars may be grouped in trays, the total nominal voltage of all cells in such a group not to exceed 250 volts, and each such tray to be supported on glass or glazed-porcelain insulators, the trays being mounted on racks supported on oil insulators with a total nominal voltage of not over 500 volts for all cells in series on each such insulated rack.

Maximum protection is secured by sectionalizing high-voltage batteries into cell groups insulated from each other.

200. Racks and Trays.—Racks and trays shall conform to the following:

1. **Racks.**—Racks, as required in this section, refer to frames designed to support cells or trays (sec. Fig. 238). They shall be substantial and made of any of the following:

a. Wood, so treated as to be resistant to deteriorating action by the electrolyte.

b. Metal, so treated as to be resistant to deteriorating action by the electrolyte and provided with nonconducting members directly supporting the cells; or with suitable insulating material on conducting members.

c. Other similar suitable construction.

2. **Trays.**—Trays refer to frames such as crates or shallow boxes usually of wood or other nonconducting material, so constructed or treated as to be resistant to deteriorating action by the electrolyte (see Fig. 239).

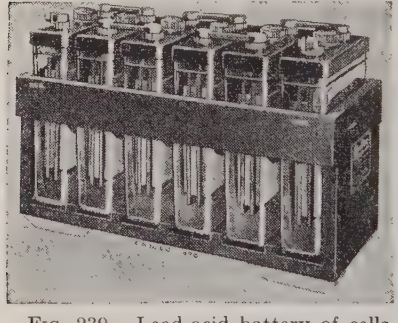


FIG. 239.—Lead-acid battery of cells in sealed glass jars mounted in a supporting tray.

201. Battery Rooms.—Battery rooms shall conform to the following:

1. **Use.**—Separate battery rooms or enclosures shall be required only for batteries in unsealed jars and tanks where the aggregate capacity at the 8-hr. discharge rate exceeds 5 kw.-hr.

2. **Wiring Method.**—In storage-battery rooms, bare conductors, open wiring, or conductors in rigid conduit or electrical metallic tubing shall be used as the wiring method.

3. **Varnished-cambric Conductors.**—Varnished-cambric-covered conductors, Type V, shall not be used.

4. **Bare Conductors.**—Bare conductors shall not be taped.

5. **Raceway.**—Rigid metal conduit, or electrical metallic tubing, if used, shall be of corrosion-resistant material or shall be suitably protected from corrosion.

6. **Terminals.**—If metal raceway or other metallic covering is used in the battery room, at least 12 in. of the conductor at the end connected to a cell terminal shall be free from the raceway or metallic covering and shall be bushed by a substantial glazed insulating bushing. The end of the raceway shall be sealed tightly to resist the entrance of electrolyte by spray or by creepage. Sealing compound, rubber insulating tape, or other suitable material shall be used for this purpose.

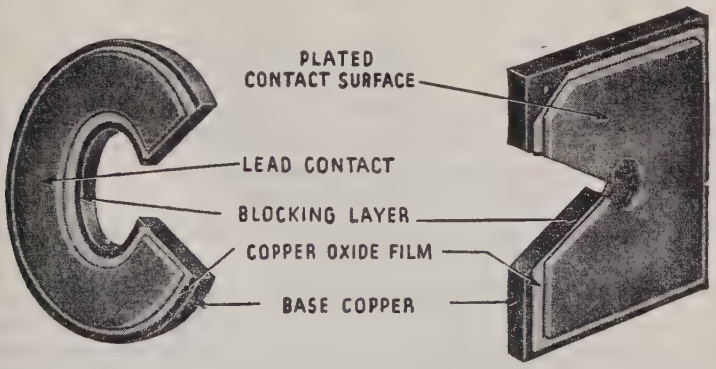
7. **Ventilation.**—Provision shall be made for sufficient diffusion and ventilation of the gases from the battery to prevent the accumulation of an explosive mixture in the battery room.

202. Danger from Gas with Storage Batteries.—The hydrogen and oxygen given off from the battery during charge, when unmixed with a

large amount of air, form a combination that will explode violently if ignited by an open flame or an electric spark. If battery is in a compartment, open or ventilate compartment while the battery is being charged, in order that these gases may become mixed with air. Do not bring exposed flame, match, cigar, etc., near the battery when charging or shortly after.

CONTACT RECTIFIERS

202A. Contact, or barrier-layer, rectifiers are devices that have the property of allowing the passage of current through the contact surface of two materials much more easily in one direction than in the other. The contact, or boundary, surface between the two materials is called the barrier, or blocking, layer. Two common types of these rectifiers are the copper oxide rectifier and the selenium rectifier. Both types are made up from series or parallel combinations of unit barrier-layer cells. In the copper oxide cell the barrier, or blocking, layer is the junction between a thin film of cuprous oxide and a copper disk. In the selenium cell the barrier, or blocking, layer is the junction between a thin layer of selenium and a layer of some conducting alloy.



I. Disk-type cell II. Plate-type cell

FIG. 239*A*.—Copper oxide rectifier cells. (*General Electric Co.*)

202B. Copper oxide cells are illustrated in Fig. 239*A*. A thin film of cuprous oxide with an outer layer of cupric oxide is produced by heating a copper disk or plate to a high temperature and quenching it in water. The cupric oxide is then removed, leaving the layer of cuprous (red) oxide on the base copper. Contact with the oxide surface can be made in either of two ways. One method is to use a lead disk, which is held against the oxide surface at a definite pressure. The other way is to deposit electrolytically a coating of a metallic conductor, such as nickel, on the oxide surface.

The junction between the base copper and the red oxide is the barrier, or blocking, layer, which permits the flow of electrons readily from copper

to oxide but tends to block the flow of electrons in the reverse direction. Considering the conventional direction of current flow, the junction will

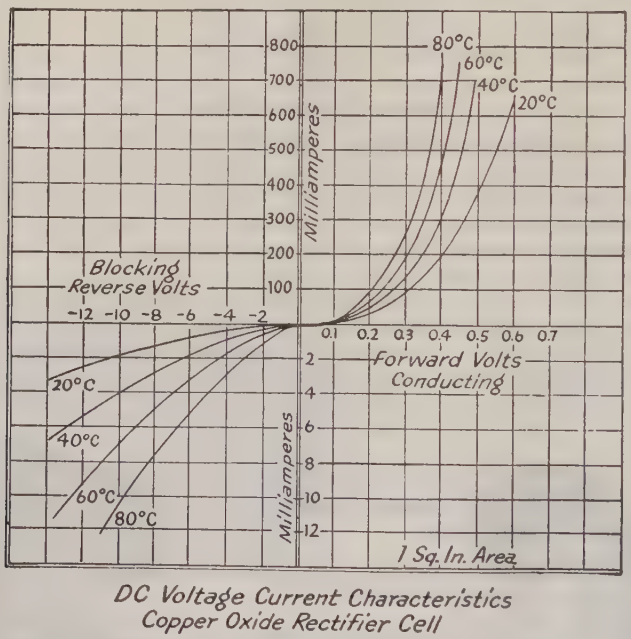


FIG. 239*B*.—D-c voltage-current characteristics of copper oxide cell. (*General Electric Co.*)

offer a high resistance to the passage of current from copper to oxide and a relatively low resistance to the passage of current from oxide to copper. In other words, conventional current passage will be in the conducting direction when the oxide is positive and the copper is negative. The rectifying characteristics are shown in Fig. 239*B*.

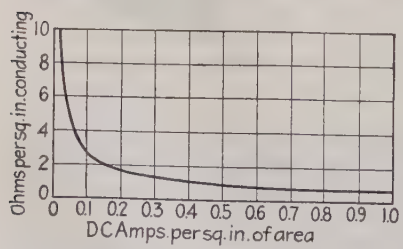


FIG. 239*C*.—Resistance current characteristics of copper oxide cell at 25°C. (*General Electric Co.*)

The copper oxide rectifier cell is a resistance device and, as such, will have a certain voltage drop when it is connected to an electric circuit. The resistance characteristic varies with current, temperature, and with time of use. The resistance decreases with increased

current, as shown in Fig. 239*C*. As the temperature increases, the resistance decreases, resulting in a lower voltage drop, as shown in Fig. 239*D*. However, at the same time the leakage current in the blocking direction increases as the temperature increases, so that the rectifying characteristic becomes poorer as the temperature increases. The resistance will

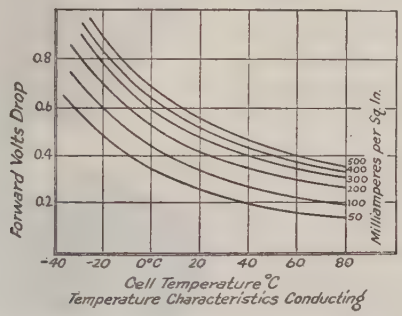


Fig. 239*D*.—Temperature characteristics of copper oxide rectifier cell when conducting. (*General Electric Co.*)

increase at first with the use of the cell but will become stable after a certain period of time, as shown in Fig. 239*E*. The voltage drop in the conducting direction will vary from approximately 0.2 to 0.9 volts depending upon the current and temperature of operation, as shown in Fig. 239*D*.

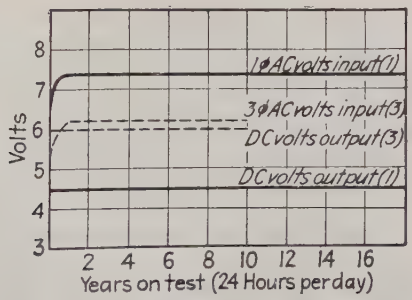


Fig. 239*E*.—Aging of copper oxide rectifiers in continuous life test. (*General Electric Co.*)

Cells are made in the disk type of construction in sizes varying from $\frac{3}{16}$ to $1\frac{1}{2}$ in. in diameter, and in the plate type of construction in two sizes of $3\frac{5}{8}$ by $4\frac{1}{2}$ in. and $4\frac{3}{8}$ by 5 in.

202C. A selenium rectifier cell consists of a metallic back plate of aluminum upon which is deposited a layer of selenium. A low-melting-point alloy is metal-sprayed onto the selenium surface. A selenium cell

is illustrated in Fig. 239*F*. The barrier, or blocking, layer is the boundary surface between the selenium layer and the sprayed-metal coating. The

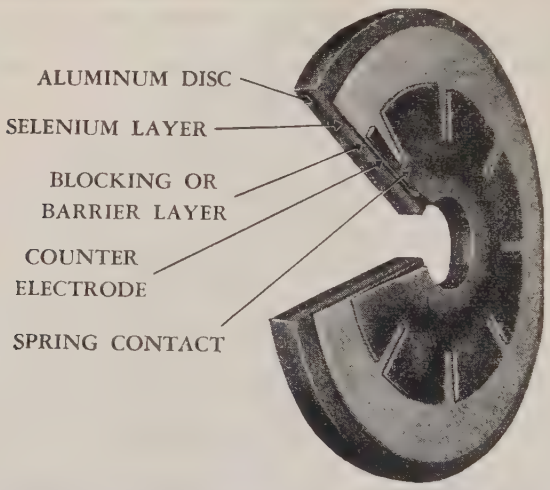


FIG. 239*F*.—Cross section of selenium rectifier cell. (*General Electric Co.*)

sprayed-metal coating is referred to as the counterelectrode. The barrier layer permits the flow of electrons readily from the counterelectrode through the selenium film to the aluminum back plate. Considering the

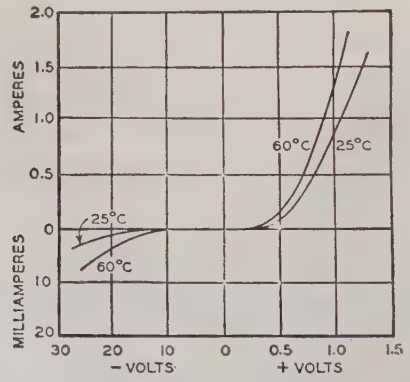


FIG. 239*G*.—D-c voltage characteristic of selenium rectifier cell. (*General Electric Co.*)

conventional direction of current flow, the junction will offer a high resistance to the passage of current from the counterelectrode to the selenium film and a relatively low resistance to the passage of current

from the selenium film to the counterelectrode. In other words, conventional current passage will be in the conducting direction when the selenium film is positive and the counterelectrode is negative. The rectifying characteristics are shown in Fig. 239*G*. The selenium cell is a resistance device and, as such, will have a certain voltage drop when it is connected to an electric circuit. The resistance characteristic varies with current and temperature. The resistance decreases with increased current. As the temperature increases the resistance decreases, result-

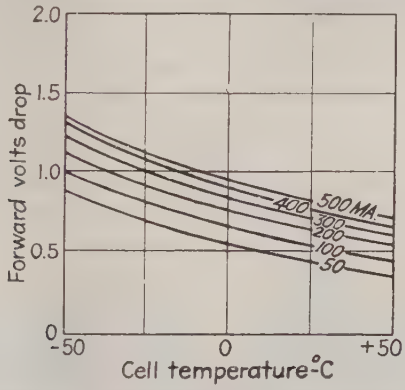


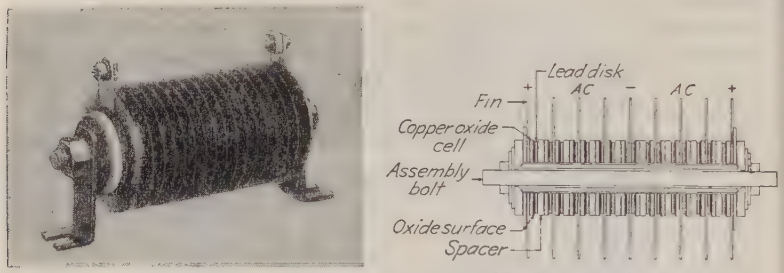
FIG. 239*H*.—Temperature characteristics of selenium rectifier cell when conducting. (*General Electric Co.*)

ing in a lower voltage drop, as shown in Fig. 239*H*. However, at the same time the leakage current in the blocking direction increases as the temperature increases, so that the rectifying characteristic becomes poorer as the temperature increases. The voltage drop in the conducting direction will vary from 0.4 to 1.2 volts, depending upon the current and temperature of operation, as shown in Fig. 239*H*. The current capacity of the cell depends upon the area of the barrier layer and the conditions of operation.

Cells are made in different sizes varying from 1 to 4⅜ in. in diameter.

202D. Rectifier Stacks.—Both copper oxide and selenium rectifier cells are arranged in stacks with a certain number of cells connected in series, depending upon the voltage requirements. Typical stack assemblies are shown in Figs. 239*I* and 239*K*. The particular arrangement of the cells within the stack is determined by the type of circuit and assembly to be used. The ones illustrated are for bridge-type rectifiers (see Sec. **202E**). Copper oxide stacks are usually provided with radiating fins as well as spacers between cells, in order to increase the dissipation of heat from the cells. For ordinary applications natural circulation of air is relied upon for the cooling of the rectifier. Where power outputs of 300

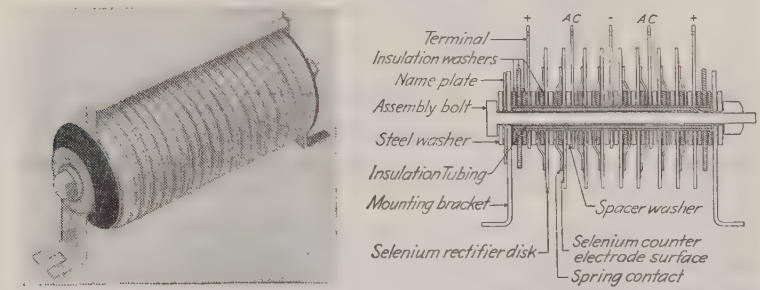
watts or more are required, it is quite customary to use forced cooling provided by means of a ventilating fan.



I. Assembly II. Cross section

FIG. 239*I*.—Copper oxide rectifier stack. (*General Electric Co.*)

Rectifier stacks can be arranged in series or parallel combinations depending upon the voltage and current requirements.



I. Assembly II. Cross section

FIG. 239*K*.—Selenium rectifier stack. (*General Electric Co.*)

202E. Rectifier Circuits.—There are various methods by which rectifiers can be connected into a circuit, and the selection will depend a great deal on the particular application. Several circuits commonly used in rectifying applications are illustrated. The simplest type of rectifier consists of an a-c power supply with a rectifier connected in series with the load as shown in Fig. 239*L*. This gives an intermittent pulsating power supply with the conducting period equal to one-half of the cycle. The actual calculation of the a-c and d-c voltage will depend on the particular rectifier characteristic. The theoretical values using a perfect rectifier will give E_{dc} equal to 0.45 E_{ac}. The a-c component, or effective heating value of the rectifier current, is equal to 1.57 times the d-c current.

If two half-wave circuits were combined, the result would be a full-wave type of rectifier, as illustrated in Fig. 239*M*. This circuit is quite

often used where low voltages are required. The transformer construction will require a mid-tap. The output is full-wave with the voltage reaching zero twice each cycle. The theortical a-c ripple in the

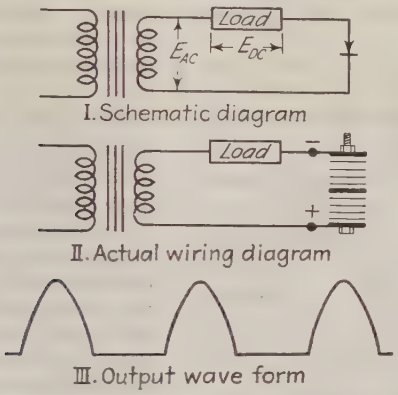


FIG. 239L.—Single-phase half-wave rectifier. (*General Electric Co.*)

output is 48 per cent. E_{dc} load voltage is equal to $0.9E_{ac}$, which is the a-c voltage measured across one-half of the transformer secondary.

By far the most common single-phase rectifier circuit is the full-wave

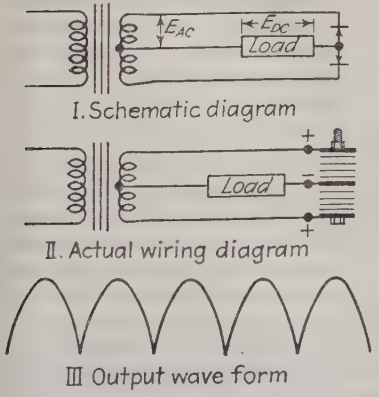


FIG. 239M.—Single-phase full-wave rectifier. (*General Electric Co.*)

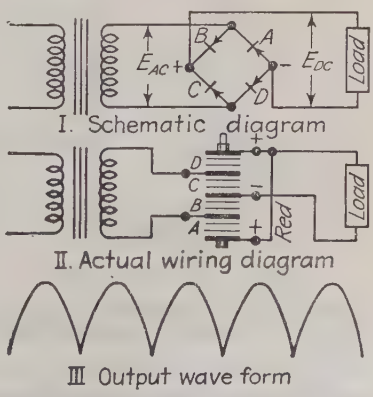


FIG. 239N.—Full-wave bridge rectifier. (*General Electric Co.*)

bridge connection shown in Fig. 239*N*. This will give the same wave shape as that shown in Fig. 239*M*, but it has the advantage in that a mid-tapped transformer is not required. In this circuit the a-c power

will flow for one-half cycle through one leg (B) of the bridge, then on through the load and back through the other leg (D) to the other side of the a-c power supply. During the other half cycle, the other two legs of the bridge circuit (A and C) will be conducting power. The value of the d-c voltage across the load E_{dc} is equal to $0.9E_{ac}$. The theoretical ripple is the same as for the full-wave mid-tapped circuit and is 48 per cent.

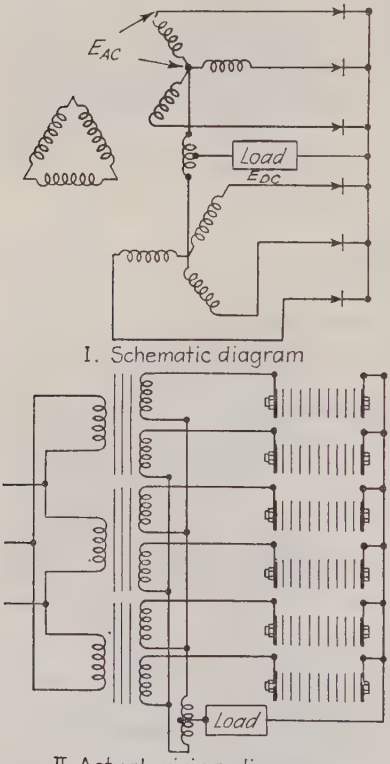


FIG. 239P.—Three-phase full-wave (double-Y) rectifier. (*General Electric Co.*)

The single-phase power supply is normally used for smaller power demands where economy of construction is important.

It is customary to use a three-phase power supply where higher power outputs are required and efficiency of operation is important. Several three-phase circuits are used, but the most common ones are illustrated. Figure 239P represents a three-phase full-wave circuit with an interphase transformer connecting the two sets of secondary circuits.

If the interphase transformer is omitted, then the rectifier circuit becomes the standard six-phase connection. The conduction period with this interphase transformer omitted is one-sixth of a cycle; and, with the interphase transformer included in the circuit, the conduction period can be increased to one-third of a cycle. By use of the interphase transformer it is possible to increase the current rating of the rectifier output. With the interphase transformer, the d-c voltage output is equal to $1.17E_{ac}$.

Without the interphase transformer, the E_{dc} is equal to $1.35E_{ac}$. Here again these values are based on a perfect rectifier without any resistance; and it is, of course, necessary to apply empirical design data in order to obtain the correct voltage value. The ripple in the d-c output is approximately 4 per cent.

The conventional three-phase circuit used in the majority of rectifier applications in shown in Fig. 239*Q* and is the three-phase full-wave bridge. This is economical and requires only three secondaries in comparison with the six secondaries required on the half-wave circuit (Fig. 239*P*). The d-c voltage output E_{dc} is equal to $2.34E_{ac}$. The conduction period is one-third of a cycle but still gives the typical six-phase ripple in the output with a theoretical magnitude of 4 per cent.

202F. Rectifier Specifications.—A contact rectifier must meet the output current and voltage requirements of the particular application. Within very definite limitations, the required current output can be met by selection of the area of the cells employed. Where greater current output is required than is allowable with a single stack, the number of stacks may be connected in parallel. The output voltage requirements are met by connecting the proper number of cells in series in each stack. The input voltage required to give the necessary output voltage is obtained by the use of a transformer of the proper voltage ratio. In ordering rectifiers, the following information should be given: voltage, frequency, and number of phases of supply circuit; d-c output voltage and current required; average temperature of location of rectifier; and the type of duty.

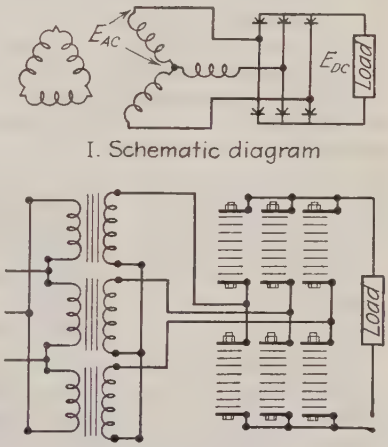


FIG. 239*Q*.—Three-phase full-wave bridge rectifier. (*General Electric Co.*)

GENERAL CONSTRUCTION MATERIALS

203. Wire nails are formed from wire of the same diameter as the shank of the nail is to be. The wire from which nails are made, hence the nail diameters, are measured by the steel-wire gage (see table in Div. 2), which is the same as the Washburn & Moen gage and is used by practically all nail manufacturers, though it is sometimes given a different name.

The size of nails is designated by the "penny" system. The penny

system[a] of designating nails originated in England. Two explanations are offered as to how this curious designation came about. One is that the sixpenny, fourpenny, tenpenny, etc., nails derived their names from the fact that 100 cost sixpence, fourpence, etc. The other explanation, which is more probable, is that 1,000 tenpenny nails, for instance, weighed 10 lb. The ancient as well as modern abbreviation for penny is "d," which is the first letter of the Roman coin denarius: the same abbreviation in early history was used for the English pound in weight. At any rate, the penny has persisted as a term in the nail industry.

Ordinary nails are made of steel wire with a natural bright-steel finish. The following special coatings, finishes, and heat-treatments may be obtained at some additional cost:

Galvanized (hot process).	Brass plated.	Blued.
Galvanized (electro).	Cadmium plated.	Annealed.
Cement coated (regular).	Nickel plated.	Oil-quench hardened.
Cement coated (clear).	Chromium plated.	Japanned.
Coppered.	Painted.	Parkerized.
Tinned.	Acid etched.	

Nails made of copper, brass, or stainless-steel wire are also available.

Nails are made in several different forms to meet the requirements of different applications. The more common types with dimensional data are given in the following sections.

204. Dimensions of Common Nails and Brads
(American Steel & Wire Co.)

Size	Length, in.	A. S. & W. gage	Approx. no. per lb.	Diam. in decimals, in.	Approx. diam., in.	Nearest B. & S. gage
2d	1	15	876	0.0720	5/64	13
3d	1¼	14	568	0.0800	5/64	12
4d	1½	12½	316	0.0985	7/64	10
5d	1¾	12½	271	0.0985	7/64	10
6d	2	11½	181	0.1130	7/64	9
7d	2¼	11½	161	0.1130	7/64	9
8d	2½	10¼	106	0.1314	1/8	8
9d	2¾	10¼	96	0.1314	1/8	8
10d	3	9	69	0.1483	9/64	7
12d	3¼	9	63	0.1483	9/64	7
16d	3½	8	49	0.1620	5/32	6
20d	4	6	31	0.1920	3/16	6
30d	4½	5	24	0.2070	13/64	4
40d	5	4	18	0.2253	7/32	3
50d	5½	3	14	0.2437	1/4	2
60d	6	2	11	0.2625	17/64	2

[a] American Steel & Wire Co.

205. Dimensions of Casing, Finishing, Shingle, and Fine Nails

(American Steel & Wire Co.)

Nail diameters are measured by the A. S. & W. gage. See Div. 1 for table. Equivalent B. & S. gage numbers and fractional-inch equivalents are given in Table 204.

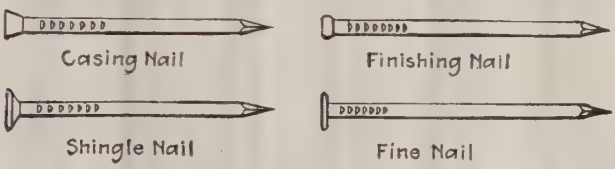


FIG. 240.—Casing, finishing, shingle, and fine nails.

Size	Length, in.	Casing		Finishing		Shingle		Fine	
		Gage	Approx. no. per lb.	Gage	Approx. no. per lb.	Gage	Approx. no. per lb.	Gage	Approx. no. per lb.
2d	1	15½	1,010	16½	1,351	....	...	16½	1,351
3d	1¼	14½	635	15½	807	13	429	15[b]	778
3½d	1⅜	....	.....	....	.....	12½	345		
4d	1½	14	473	15	584	12	274	14	473
5d	1¾	14	406	15	500	12	235		
6d	2	12½	236	13	309	12	204		
7d	2¼	12½	210	13	238	11	139		
8d	2½	11½	145	12½	189	11	125		
9d	2¾	11½	132	12½	172	11	114		
10d	3	10½	94	11½	121	10	83		
12d	3¼	10½	87	11½	113				
16d	3½	10	71	11	90				
20d	4	9	52	10	62				
30d	4½	9	46						
40d	5	8	35						
2d[a]	1	....	.....	....	.....	....	...	17	1,560
3d[a]	1⅛	....	.....	....	.....	....	...	16	1,015

[a] These sizes are called Extra Fine.

[b] This nail is only 1⅛ in. long.

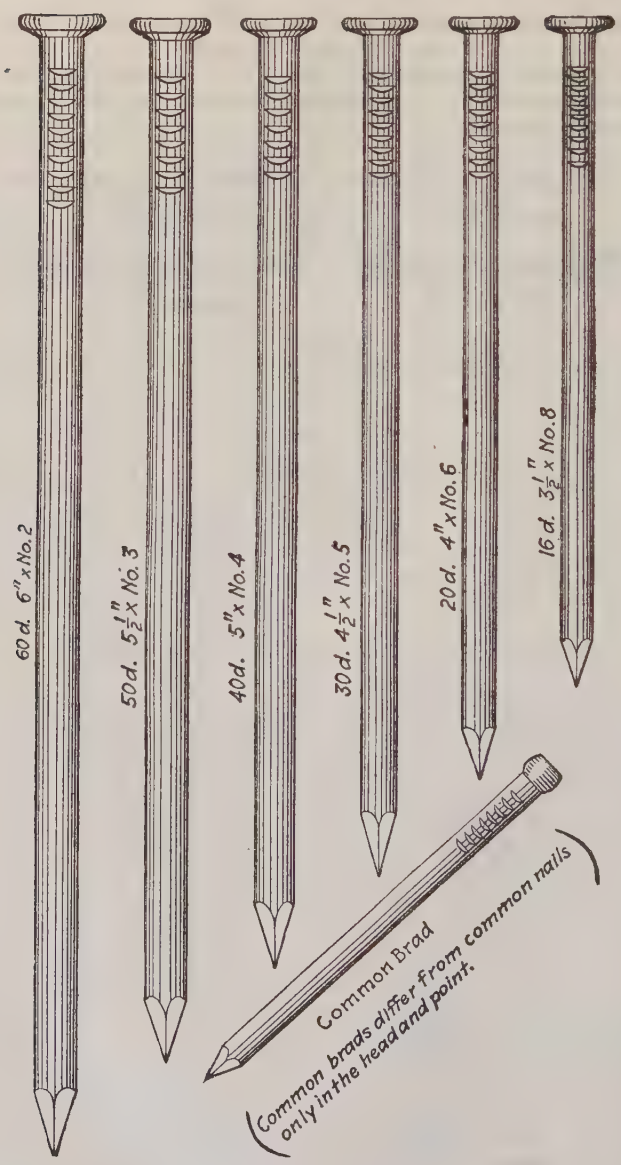


FIG. 241.—Common nails (actual size).

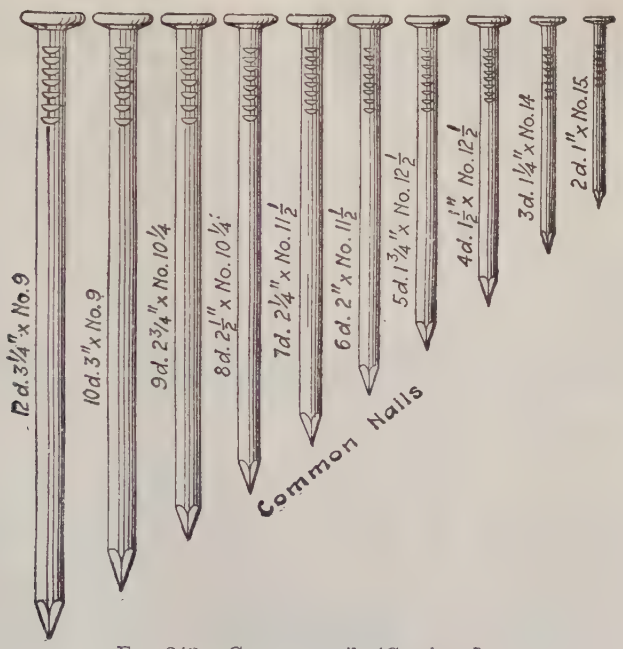


FIG. 242.—Common nails (*Continued*).

206. Dimensions of Wood Screws

Roundheaded wood screws do not measure full length but are from 1/16 to 3/16 in. short. For example, a No. 4 by 1/2-in. roundheaded wood screw measures about 7/16 in. long under the head, and a No. 20 by 2-in. screw measures about 1 7/8 in. under the head.

207. Wood Screws.—Diameters are measured by the American Screw Co.'s gage, and range in size from No. 0 to No. 30. They range in length from 1/4 to 6 in. The increase in length is by eighths of an inch up to 1 in., then by quarters of an inch up to 3 in., and by half inches up to 5 in. Manufacturers' standards vary, but generally the threaded portion is approximately seven-tenths of the total length. There is no standard number of threads per inch for the products of all manufacturers. The gage and diameter refer to the unthreaded portion of the screw. They are available in three types of head (Fig.

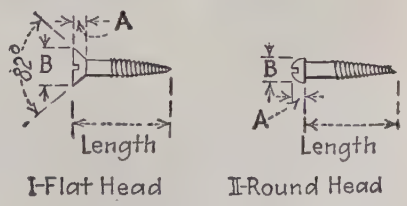


FIG. 243.—Wood screws.

243): flat, round, and oval. The oval head (see illustration for machine screws, Fig. 244) is used for especially high-grade work such as cabinet-work, which must present a very neat appearance.

The ordinary materials used for making wood screws are steel and brass. The flat-headed screws are regularly available in steel, with a

(Refer to Fig. 243.)

Screw gage No.	Diam., in.			Flat head		Round head			Clearance drill		Greatest length obtainable, in.
	In decimals	In fractions	Nearest B. & S. gage	*A*	*B*	*A*	*B*	Counterbore for head	No.	Diam. in.	
0	0.05784	1/16 −	15	1/16	7/64 +	....	....	....	.....	....	1/4
1	0.07100	5/64 −	14	1/16	9/64 −	....	....	....	.....	.....	1/2
2	0.08416	5/64 +	12	1/16	5/32 +	1/16	13/64	7/32	44	0.086	7/8
3	0.09732	3/32 +	11	1/16	3/16	5/64	13/64	....	.....	.....	1 1/2
4	0.11048	7/64 +	9	1/16	7/32 −	5/64	13/64	7/32	33	0.113	1 1/2
5	0.12364	1/8 −	8	1/16	15/64 +	3/32	15/64	....	.....	.....	2 1/2
6	0.13680	9/64 −	7	5/64	17/64 +	3/32	1/4	17/64	28	0.1415	3
7	0.14996	5/32 −	7	3/32	19/64 −	7/64	3/32	....	.....	.....	3
8	0.16312	5/32 +	6	7/64	5/16 +	7/64	19/64	5/16	18	0.1695	4
9	0.17628	11/64 +	5	7/64	11/32 +	1/8	21/64	....	.....	.....	4
10	0.18944	3/16 +	5	7/64	3/8 −	1/8	11/32	23/64	10	0.1935	4
11	0.20260	13/64 −	4	1/8	25/64 +	9/64	3/8	....	.....	.....	4
12	0.21576	7/32 +	4	1/8	27/64	5/32	25/64	13/32	7/32	0.2188	6
13	0.22892	15/64 −	3	1/8	29/64	5/32	27/64	....	.....	.....	6
14	0.24208	1/4 −	3	9/64	15/32 +	5/32	29/64	29/64	1/4	0.250	6
15	0.25524	1/4 +	2	9/64	1/2	11/64	29/64	....	.....	.....	6
16	0.26840	17/64 +	2	5/32	17/32 −	11/64	31/64	....	.....	.....	6
17	0.28156	9/32	1	5/32	35/64 +	11/64	1/2	....	.....	.....	6
18	0.29472	19/64 −	1	11/64	37/64	3/16	17/32	35/64	.....	0.302	6
19	0.30788	5/16 −	0	3/16	39/64 −	....	17/32	....	.....	.....	6
20	0.32104	21/64 −	0	13/64	5/8 +	13/64	9/16	37/64	.....	0.323	6
21	0.33420	21/64 +	0	13/64	21/32	13/64	19/32	....	.....	.....	6
22	0.34736	11/32 +	0	13/64	11/16 −	7/32	5/8	....	.....	.....	6
23	0.36052	23/64 +	2/0	7/32	45/64 +	7/32	41/64	....	.....	.....	6
24	0.37368	3/8 −	2/0	7/32	47/64	15/64	21/32	43/64	.....	0.377	6
25	0.38684	25/64 −	3/0	7/32	49/64 −	15/64	11/16	....	.....	.....	6
26	0.40000	13/32 −	3/0	15/64	25/32 +	1/4	45/64	....	.....	.....	6
27	0.41316	13/32 +	3/0	19/64	13/16	1/4	23/32	....	.....	.....	6
28	0.42632	27/64 +	3/0	1/4	27/32	1/4	47/64	....	.....	.....	6
29	0.43948	7/16 +	4/0	1/4	55/64 +	17/64	3/4	....	.....	.....	6
30	0.45264	29/64	4/0	17/64	57/64	9/32	25/32	....	.....	.....	6

Depth of hole = height of head *A*

natural bright finish or galvanized, and in brass. The roundheaded screws are made of steel, with a blued or nickel-plated finish, and of brass. The oval-headed screws are regularly made only of brass with a nickel-plated finish.

208. Machine Screws.—Diameters are designated by the American Screw Co.'s gage and range in size from No. 2 to No. 34. They range in length from $\frac{1}{8}$ to 4 in. The increase in length is by sixteenths of an inch up to 1 in., by eighths of an inch up to 2 in., and by quarters of an inch up to 4 in. The threaded portion either extends over all or nearly all the total length. Machine screws are designated by their gage number and number of threads per inch. A No. 10-24 screw has a

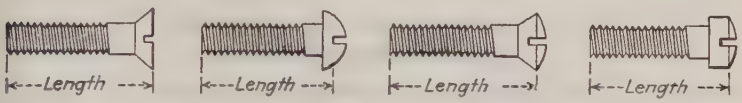


FIG. 244.—Machine screws.

diameter corresponding to size No. 10 of the American screw gage and has 24 threads per inch. The gage number refers to the diameter over the thread. They are available with heads of four different types: flat, round, oval, and fillister (Fig. 244). The length of flat-headed screws is measured over-all, the length of roundheaded ones includes about one-half of the head, the length of oval-headed screws includes the countersinks, and the length of fillister-headed ones is measured from the rim of the head.

Standard machine screws are made of iron or brass. The iron screws may be provided with any one of the following finishes: natural bright, blued, nickel, brass or silver plated, silver or copper oxidized, various bronzes, japanned, lacquered, coppered, tinned, galvanized, bower barffed, or gun metal.

209. Data for Machine Screws

Screw gage No.	Diam., in.	Standard threads per in.	Screw gage No.	Diam., in.	Standard threads per in.
2	0.08416	48, 56, or 64	12	0.21576	20 or 24
3	0.09732	48 or 56	14	0.24208	18, 20, or 24
4	0.11048	32, 36, or 40	16	0.26840	16, 18, or 20
5	0.12364		18	0.29472	
6	0.13680	30, 32, or 36	20	0.32104	16 or 18
7	0.14996	30 or 32	24	0.37368	14, 16, or 18
8	0.16312	30, 32, or 36	30	0.45264	14 or 16
9	0.17628	24, 30, or 32	34	0.50528	13
10	0.18944				

210. Machine Bolts and Nuts.—Machine bolts are designated by the diameter of the shank of the bolt. They range in lengths from 1½ to 30 in. The increase in length is by half inches up to 8 in., and by inches

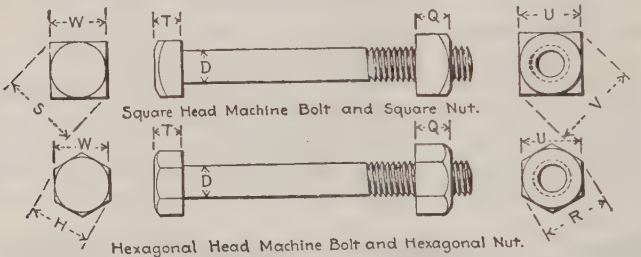


FIG. 245.—Machine bolts and nuts.

up to 30 in. Bolts are regularly furnished with one nut. The standard number of threads per inch for the bolts and nuts are as follows:

Diam.	¼	5/16	⅜	7/16	½	9/16	⅝	11/16	¾	⅞	1
No. of threads per in.	28	24	24	20	20	18	18	16	16	14	14

Bolts are made with either square or hexagonal heads and may be furnished with nuts of the corresponding shape. They are made of iron and may be finished with a natural black or galvanized coating.

211. Dimensions and Strengths of Machine Bolts and Nuts
(Refer to Fig. 245.)

D	T	W	S	H	Q	U	R	V	Safe tensile strength of bolt at root of thread at 6,000 lb. per sq. in.	Safe shearing strength at 7,500 lb. per sq. in.	
										Full bolt	Root of thread
¼	8/16	⅜	17/32	7/16	3/16	7/16	½	⅝	160	370	200
5/16	15/64	15/32	21/32	35/64	¼	17/32	⅝	¾	270	575	340
⅜	9/32	9/16	51/64	21/32	5/16	⅝	47/64	57/64	410	830	510
7/16	21/64	21/32	15/16	¾	⅜	23/32	27/32	1 5/64	560	1,130	700
½	⅜	¾	1 1/16	27/32	7/16	13/16	61/64	1 5/32	760	1,470	940
⅝	15/32	15/16	121/64	1 5/64	9/16	1	1 5/32	127/64	1,210	2,300	1,510
¾	19/32	1 ⅛	119/32	119/64	11/16	1 3/16	1 ⅜	143/64	1,810	3,310	2,260
⅞	21/32	1 5/16	155/64	1 ½	13/16	1 ⅜	119/32	161/64	2,520	4,510	3,140
1	¾	1 ½	1 ½	147/64	15/16	1 9/16	113/16	2 7/32	3,300	5,890	4,130
1⅛	27/32	111/16	225/64	131/32	1 ⅛	113/16	2 3/32	2 9/16	4,160	7,450	5,200
1¼	15/16	1 ⅞	221/32	2 5/32	1 ¼	2	2 5/16	227/32	5,350	9,200	6,670
1⅜	1 1/32	2 1/16	259/64	225/64	1 ⅜	2 7/16	211/32	3 3/32	6,340	11,130	7,900
1½	1 ⅛	2 ¼	3 5/16	219/32	1 ½	2 ⅜	247/64	3 ⅜	7,770	13,250	9,700
1⅝	1 1/32	2 7/16	3 ¾	213/16	1 ⅝	2 9/16	231/32	3 ⅝	9,090	15,550	11,360
1¾	1 5/16	2 ⅝	323/32	3 1/32	1 ¾	2 ¾	3 5/16	357/64	10,470	18,000	13,080
1⅞	113/32	213/16	363/64	3 ¼	1 ⅞	215/16	225/64	4 5/32	12,300	20,700	15,370
2	1½	3	4 ¼	315/32	2	3 1/16	3 5/8	427/64	13,800	23,560	17,250

212. Data on carriage bolts are given in Div. 8.

213. Toggle bolts, which are used for fastening raceways and electrical devices to hollow tile or plaster-on-metal-lath surfaces, are of two general

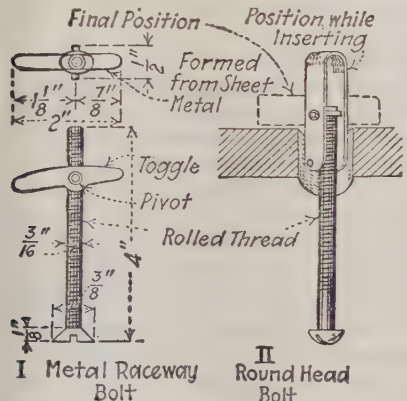


Fig. 246.—Screw-type toggle bolts.

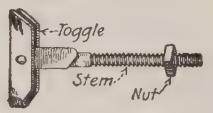


Fig. 247.—Nut-type toggle bolt.

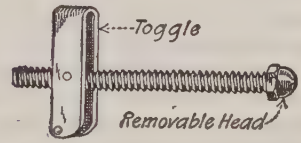
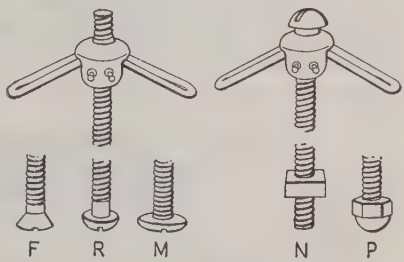


Fig. 248.—Plumbers' toggle bolt.

types. The screw type (Fig. 246) is the most frequently used but has the disadvantage that if it is ever necessary to remove the screw entirely, the toggle is lost within the wall. Where the object fastened must be removed and replaced a nut-type toggle bolt (Figs. 247 and 248) can be used. When the type of Fig. 247 is used it is usually necessary, after the device is in place, to cut off the part of the bolt that extends, so as to give a neat appearance. The so-called plumbers' toggle bolt (Fig. 248) has a removable, hexagonal cap so that the device can be inserted in the wall before the object to be fastened is slipped over the bolt. Then, on putting the cap in place, the whole bolt is backed into the wall, hiding the surplus thread from view. Cone-headed toggles (Fig. 249) are used principally for the erection of metal raceway and have the advan-

Fig. 249.—Toggle bolt for metal raceway.



R—with round-head screw
F—with flat-head screw
M—mushroom head, furnished in 1/8-in. diameter only
N—reverse R or F screw and add nut on any size.
P—plumbers' toggle; reverse R or F screw and add cap nut on any size

Fig. 250.—Spring-in toggle bolt.

tage that the toggle head will readily pass through the hole in the raceway backing. A spring-in type of toggle bolt is shown in Fig. 250. The wings are tempered spring steel having a cam action against the saddle which throws them to the open position. Toggle bolts are made in several diameters and lengths.

214. Lag screws are discussed in Div. 8.

215. Expansion sleeves, shields, and bolts are used for attaching equipment and devices to stonelike materials such as concrete, brick, tile, etc. They are made in a variety of types and consist of a lead sleeve or malleable-iron expansion shield which is inserted in a hole cut in the masonry. The equipment to be supported is attached to the sleeve or shield by means of a wood, machine, or lag screw, depending upon the design of the sleeve or shield. As the screw is turned into the sleeve or shield, it expands the body of the sleeve or shield against the sides of the hole in the masonry so that it grips the masonry with considerable holding power. These devices are called by various trade names such as expansive anchors, expansion sleeves, expansion screws, or expansion bolts and anchors. Data and illustrations of some common types are given in the following sections.

216. Diamond Multisize Screw Anchors

These are designed to accommodate in one anchor several diameters of wood screws. The purpose is to reduce the number of anchors required to accommodate all sizes of screws. They are made in several lengths covering the majority of uses and are put up in boxes of 100.

FIG. 251.

For wood screws, No.	Length, in.	Size of drill, in.	Weight, lb. per 100
6– 8	¾	¼	1
6– 8	1½	¼	1¾
10–14	¾	5/16	1½
10–14	1	5/16	2
10–14	1½	5/16	2¾
16–18	1	⅜	3
16–18	1½	⅜	4¼
20–24	1¾	7/16	5¼

217. Diamond Calking Anchors for Use with Machine Screws

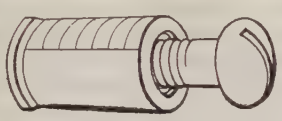


FIG. 252.

Diam. of bolt or screw	Hole size, in.		Suggested safe load, lb.	Weight, lb. per 100
	Diam.	Depth		
6–32	1/4	3/8	80	1
8–32	5/16	1/2	90	1 1/2
10–24	3/8	5/8	175	2
12–24	7/16	3/4	320	3 1/2
1/4–20	1/2	7/8	400	4 1/2
5/16	5/8	1	480	11
3/8	3/4	1 1/4	720	16
7/16	7/8	1 1/2	950	24
1/2	7/8	1 1/2	1,000	24
5/8	1	2	1,250	41

Calking anchors are put up in standard packages of 100 for sizes No. 10-24 and smaller, and in packages of 50 for sizes No. 12-24 and larger. One calking tool is in each box. All suggested safe loads are based on ideal conditions.

218. Ackerman-Johnson Expansive Screw Anchors

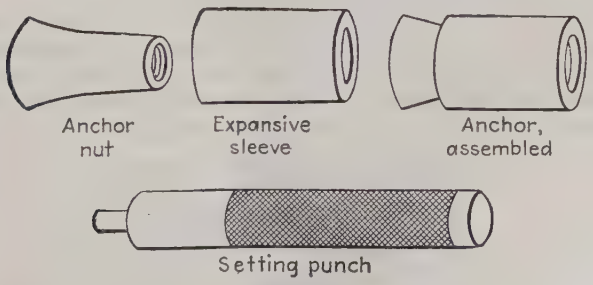


FIG. 253.

The Ackerman-Johnson expansive screw anchor consists of a hard, biconoidal, internally threaded nut, within a lead-composition expansive sleeve. It is used for attaching fixtures or wiring to any stonelike material as concrete, brick, tile, etc.

Method of Installing Anchor.—When installed, the sleeve is driven farther toward the base of tapered nut, being thereby expanded and swedged tightly against the sides of the hole, giving perfect holding contact throughout the length and circumference of the anchor.

To determine the size anchor best suited for the work, first select the screw or bolt to be preferred and then anchors of corresponding size number; for example, for work demanding No. 10-24 screws, specify No. 10-24 anchor; if ⅜-in. bolts are required, use No. ⅜-in. anchor.

A setting punch is included with every package of 50 or 100 anchors.

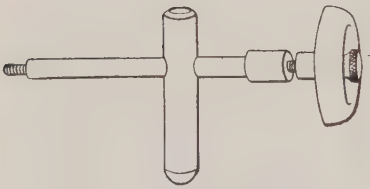


Fig. 254.—Hammerless setting tool.

Anchor size No.	Minimum dimensions of holes required, in.		Shipping weight, lb. per 1,000
	Diam.	Depth	
6-32	¼	⅜	7½
8-32	5/16	½	15
10-24	⅜	⅝	22½
12-24	7/16	¾	34
¼-20	½	⅞	50½
5/16-18	⅝	1	95
⅜-16	¾	1¼	162
7/16-14	⅞	1½	221
½-13	⅞	1½	231
⅝-11	1⅛	2	512

Hammerless Setting Tool.—Anchors are set perfectly, in tile or other thin materials in which the hole extends through or has a weak bottom, by means of the hammerless setting tool (see Fig. 254).

The stud is screwed into the anchor, which is then inserted in position; turning the wheel moves the threaded stud rearward, thus drawing the anchor nut into its ductile sleeve, expanding the latter to any degree required for safe anchorage. The tool is furnished in sizes to use with the following sizes of anchor: 8-32, 10-24, 12-24, and ¼-20.

219. Diamond Lag-screw Shield

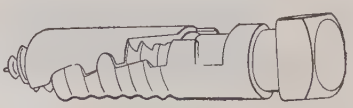


Fig. 255.

The lag-screw shield is made of malleable iron in two wedge-shaped halves. The outer wedge slides forward when the screw is turned, creating a powerful expansion. The shield is galvanized by Diamond hot-dip process.

Diam. screw, in.	Outside diam. and drill required, in.	Standard package	Long standard pattern		Short standard pattern	
			Length shield, in.	Shipping weight, lb.	Length shield, in.	Shipping weight, lb.
¼	½	100	1½	4½	1	3
5/16	½	100	1¾	5	1¼	3
⅜	⅝	100	2¼	10	1¾	7½
½	¾	100	3	16	2	10
⅝	⅞	100	3½	21		
¾	1	50	3½	24		

220. Interlocking Keystone Expansion Shields (for use with machine bolts or machine screws).

Diam., in.	Length, in.	Outside diam. and drill required, in.	Weight, lb. per 100	Diam., in.	Length, in.	Outside diam. and drill required, in.	Weight, lb. per 100
¼	1½	½	6	½	1 5/16	½	6
5/16	1¾	9/16	7	5/16	1½	9/16	6
⅜	2	11/16	11	⅜	1⅝	11/16	10
7/16	2½	⅞	16	½	1⅞	⅞	16
½	2½	⅞	20	⅝	2	1	20
⅝	2⅞	1	29	¾	2¾	1 3/16	46
¾	3¼	1 ⅛	52				
⅞	4	1 ½	88				
1	4¼	1 ⅝	114				
1¼	6	2 ⅛	300				
1½	7½	2 ½	450				

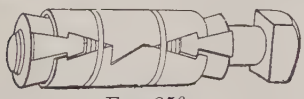


FIG. 256.

Double

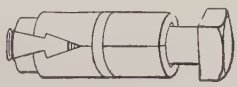


FIG. 257.

Single

221. Rawlplugs (Fig. 258) are made from stiffened strands of jute fiber. The fiber strands are compressed together by a patented process. Once in place, a Rawlplug can never crumble or pulp. It is unaffected by moisture or change in temperature.

The screw entering the Rawlplug automatically threads it, which permits removal and replacement of screw as often as desired without stripping the threads so formed. The screw cannot be withdrawn by direct or indirect pull.

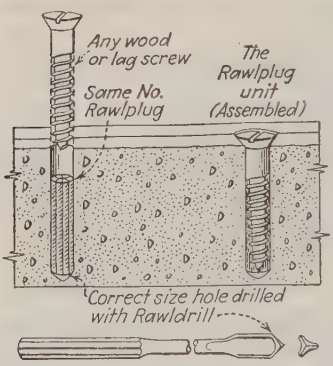


FIG. 258.—Installation of Rawlplugs.

Rawlplugs require only a small hole. This makes installation easy and assures a neat job. The Rawlplug is invisible when in position, as the diameter of the hole and Rawlplug is smaller than the head of the screw, giving the screw the appearance of being screwed into the masonry itself.

Owing to the composition, Rawlplugs resist and absorb shocks. They cannot work loose, slip, sheer, or lose their viselike grip. When properly inserted the Rawlplug should develop the entire strength of the screw or of the surrounding material, such as concrete, brick, stone, slate, marble, plaster, glass, hard rubber, gypsum block, wall-board, terra cotta, composition walls and floors, wood, and metal.

They are made in the sizes listed below in lengths of $\frac{5}{8}$, $\frac{3}{4}$, 1, $1\frac{1}{4}$, $1\frac{1}{2}$, 2, $2\frac{1}{2}$, 3, and $3\frac{1}{2}$ in.

Rawlplug No.	Use with screw No.	Diam. drill required, in.	Rawldrill No. (not diam.)	Use with tool holder No.	Size twist drill, in.
Rawlplug, Rawldrill, and Tool-holder Size Data					
6	5-6	$\frac{5}{32}$	6	14	$\frac{5}{32}$
8	7-8	$11\frac{3}{64}$	8	14	No. 15
10	9-10	$\frac{3}{16}$	10	14	No. 10
12	11-12	$\frac{1}{4}$	12	14	$\frac{1}{4}$
14	14[a]	$\frac{9}{32}$	14	14	$\frac{9}{32}$
16	16[a]	$\frac{5}{16}$	16	20	$\frac{5}{16}$
20	20[b]	$\frac{3}{8}$	20	20	$\frac{3}{8}$
Lag-screw Sizes[c]					
$\frac{3}{8}$	$\frac{3}{8}$	$\frac{7}{16}$			
$\frac{7}{16}$	$\frac{7}{16}$	$\frac{1}{2}$			
$\frac{1}{2}$	$\frac{1}{2}$	$\frac{5}{8}$			
$\frac{5}{8}$	$\frac{5}{8}$	$\frac{3}{4}$			

[a] Or $\frac{1}{4}$-inch lag screw.

[b] Or $\frac{5}{16}$-inch lag screw.

[c] For $\frac{1}{4}$-in. lag screw use No. 14 or No. 16 Rawlplug. For $\frac{5}{16}$-in. lag screw use No. 20.

222. Rawl-drives (Fig. 259) consist of a high-grade, heat-treated steel pin with a flat head and split expanded central portion, which, when driven in, grips the side of the hole with a spring action. They are easily and quickly installed, since they drive like a nail into a drilled hole no

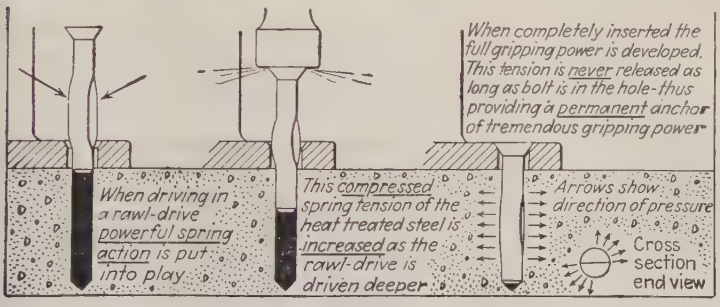


FIG. 259.—Illustration of principle of Rawl-drive.

larger than the diameter of the pin itself. They are for use only in solid masonry of brick, concrete, or stone. They should not be used in soft or brittle materials, such as plaster, wood, composition wood, glass, tile, etc. The manufacturer specifies that they have the following holding powers:

Holding Power of Rawl-drives

Size Rawl-drive, in.	Average direct pull, lb.	
	1-2-4 concrete	Common brick
3/16 × 1 1/4	1,200	634
1/4 × 1 1/2	2,325	1,183
5/16 × 2 1/4	4,025	1,833
3/8 × 2	6,450	2,150
1/2 × 3	12,526	3,700

223. Data for Rawl-drives

Diam. of bolt and drill, in.	Length of bolt, in.	Use Rawldrill No. or size	Packed[a] in boxes of	Approx. weight, lb. per 100 bolts
3/16	1	No. 8	100	1 3/4
3/16	1 1/4	No. 8	100	2
1/4	1 1/4	No. 12	100	3
1/4	1 1/2	No. 12	100	3 1/2
1/4	2	No. 12	100	4
5/16	1 1/2	No. 16	50	6
5/16	2	No. 16	50	7
5/16	2 1/2	No. 16	50	8
5/16	3	No. 16	50	9
3/8	2	No. 20	25	10
3/8	2 1/2	No. 20	25	12
3/8	3	No. 20	25	13
3/8	3 1/2	No. 20	25	15
1/2	3	1/2 in.	25	25
1/2	3 1/2	1/2 in.	25	28
1/2	4	1/2 in.	25	30

[a] A standard package consists of four boxes of the same size, length and type.

DIVISION 5

TRANSFORMERS

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CONSTRUCTION, TYPES, AND CHARACTERISTICS

1. A transformer is an apparatus for converting electrical power in an a-c system at one voltage or current into electrical power at some other voltage or current without the use of rotating parts.

2. A constant-potential transformer (Fig. 1) consists essentially of three parts: the primary coil which carries the alternating current from the supply lines; the core of magnetic material in which is produced an alternating magnetic flux; and the secondary coil in which is generated an e.m.f. by the change of magnetism in the core which it surrounds.

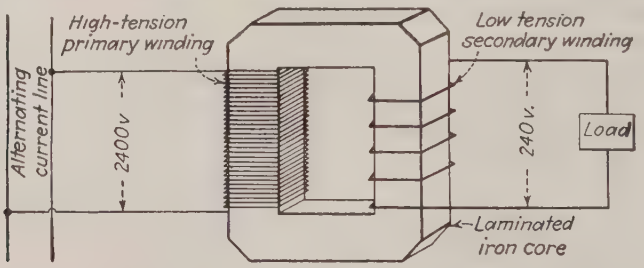


FIG. 1.—The elementary transformer.

Sometimes the transformer may have only one winding, which will serve the dual purpose of primary and secondary coils.

The high-tension winding is composed of many turns of relatively fine copper wire, well insulated to withstand the voltage impressed on it. The secondary winding is composed of few turns of heavy copper wire capable of carrying considerable current at a low voltage.

3. Transformer Terminology.—The **primary winding** is the winding of the transformer which is connected to the source of power. It may be either the high- or the low-voltage winding, depending upon the application of the transformer.

The **secondary winding** is the winding of the transformer which delivers power to the load. It may be either the high- or the low-voltage winding, depending upon the application of the transformer.

The **core** is the magnetic circuit upon which the windings are wound.

The **high-tension winding** is the one which is rated for the higher voltage.

The **low-tension winding** is the one which is rated for the lower voltage.

A **step-up transformer** is a constant-potential transformer so connected that the delivered voltage is greater than the supplied voltage.

A **step-down transformer** is one so connected that the delivered voltage is less than that supplied; the actual transformer may be the same in one case as in the other, the terms step-up and step-down relating merely to the application of the apparatus.

4. Transformer Cores.—Until recently all transformer cores were made up of stacks of sheet-steel punchings firmly clamped together. One

FIG. 2.—Assembly of transformer-core laminations. (*Wagner Electric Corp.*)

method of assembly and clamping of the sheets is shown in Figs. 2 and 3. Sometimes the laminations are coated with a thin varnish in order to reduce eddy-current losses. When the laminations are not coated with varnish, a sheet of insulating paper is inserted between laminations at regular intervals.

A new type of core construction has been developed by the General Electric Co. and is known as Spirakore. Each core consists of a continuous strip of silicon steel which is wound in a tight spiral around the insulated coils and firmly held by spot welding at the end. The core and windings of a Spirakore transformer are shown in Fig. 4. This type of construction reduces the cost of manufacture and reduces the power loss in the core due to eddy currents.

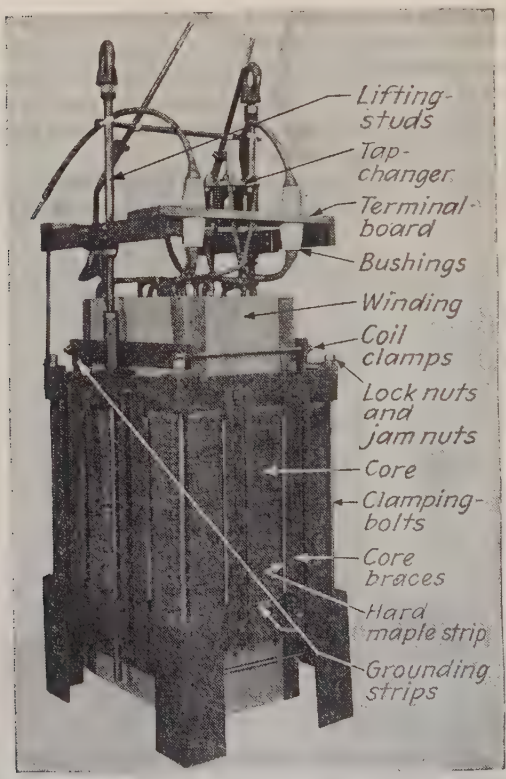


FIG. 3.—Transformer assembly. (*Wagner Electric Corp.*)

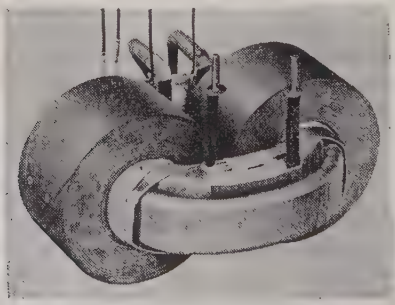


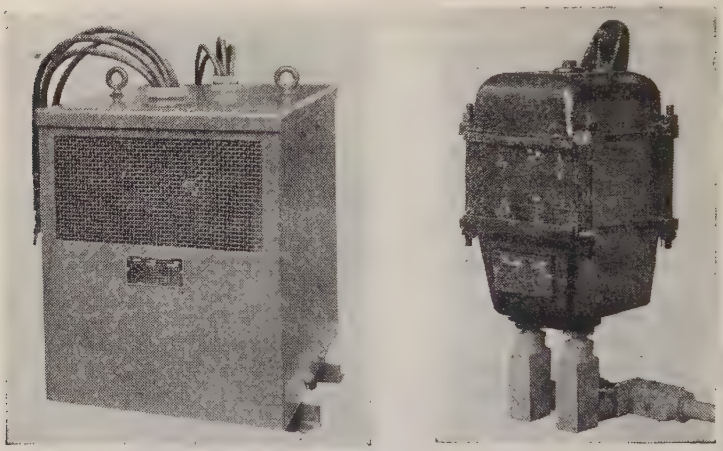
FIG. 4.—Assembled core and coils, without clamps, for wound-core distribution transformer. (*General Electric Co.*)

5. Classification of Transformers.

1. According to method of cooling.
   - *a.* Self-air-cooled.
   - *b.* Air-blast-cooled.
   - *c.* Liquid-immersed, self-cooled.
   - *d.* Oil-immersed, combination self-cooled and air-blast.
   - *e.* Oil-immersed, water-cooled.
   - *f.* Oil-immersed, forced-oil-cooled.
   - *g.* Oil-immersed, combination self-cooled and water-cooled.
2. According to insulation between windings.
   - *a.* Windings insulated from each other.
   - *b.* Autotransformers.
3. According to number of phases.
   - *a.* Single-phase.
   - *b.* Polyphase.
4. According to method of mounting.
   - *a.* Pole and platform.
   - *b.* Subway.
   - *c.* Vault.
   - *d.* Special.
5. According to purpose.
   - *a.* Constant potential.
   - *b.* Varying potential.
   - *c.* Current.
   - *d.* Constant current.
6. According to service.
   - *a.* Large power.
   - *b.* Distribution.
   - *c.* Small power.
   - *d.* Sign lighting.
   - *e.* Control and signaling.
   - *f.* Gaseous-discharge-lamp transformers.
   - *g.* Bell ringing.
   - *h.* Instrument.
   - *i.* Constant current.
   - *j.* Series transformers for street lighting.

6. Cooling of Transformers.—A certain amount of the electrical energy delivered to a transformer is transformed into heat energy due to the resistance of its windings and to the hysteresis and eddy currents in the iron core. Means must be provided for removing this heat energy from the transformer and dissipating it into the surrounding air. If this is not done in a satisfactory manner, the transformer would operate at an excessively high temperature, which would destroy or harm the insulation of the transformer. The different methods of cooling employed are listed in Sec. **5** and described below.

In **self-air-cooled** transformers (Fig. 5) the windings are simply surrounded by air at atmospheric pressure. The heat is removed by natural convection of the surrounding air and by radiation from the different parts of the transformer structure. Air cooling has long been employed for transformers of very small capacity. The development of satisfactory coil insulation materials, such as porcelain, mica, glass, and asbestos, which will withstand higher temperatures than the more common insulating materials, has made possible the application of air cooling to transformers of large capacity. Except in the smaller sizes, the



I. With grating in cover to aid circulation of air around element.

II. With solid metal casing.

FIG. 5.—Self-air-cooled transformers. (*Wayner Electric Corp.*)

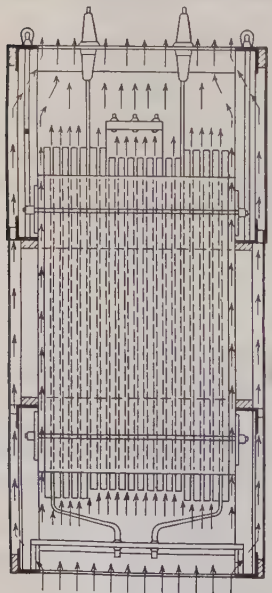


FIG. 6.—Longitudinal section of air-blast transformer, showing direction of air currents

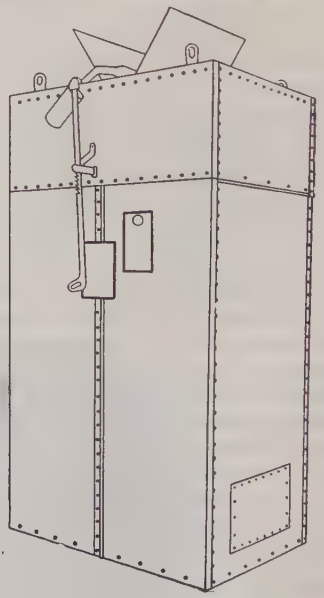


FIG. 7.—Exterior view of 1,330 kva. air-blast transformer showing the sheet steel casing.

sheet-metal enclosure is provided with louvers or gratings to allow free circulation of the air over and through the windings. Self-air-cooled transformers are sometimes called dry-type transformers. The present-day use of self-air-cooled transformers has been extended to units of at least 3,000-kva. capacity at 15,000 volts.

In **air-blast-cooled** transformers (Figs. 6 and 7) the core and windings are enclosed in a metal enclosure through which air is circulated by means of a blower. This method has been used for large power transformers in ratings up to 15,000 kva. with voltages not exceeding 35,000.

FIG. 8.—Small distribution transformer with smooth tank, equipped with hangers for pole mounting. (*Maloney Electric Co.*)

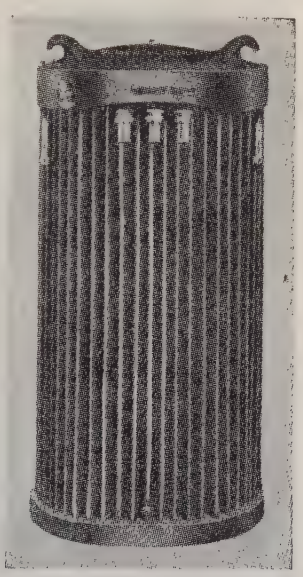


FIG. 9.—Medium-sized transformer (large subway-distribution type) with corrugated tank. (*Maloney Electric Co.*)

In **liquid-immersed, self-cooled transformers,** the core and windings re immersed in some insulating liquid and enclosed in a metal tank. The liquid, in addition to providing some of the required insulation etween the windings, carries the heat from the core and windings to the urface of the tank. The heat is then removed into the surrounding tmosphere by natural convection of the surrounding air and by radiation rom the tank. In the smaller sizes the tanks have a smooth surface Fig. 8). In larger sizes the tanks are corrugated (Fig. 9) or provided ith external tubes (Fig. 10), and in very large units the tanks must be pplied with external radiators (Fig. 11), through which the oil circulates y natural convection due to differences in temperature in the liquid.

This method may be employed for units of any size or voltage rating, although large-capacity units become rather expensive and bulky. The common liquid employed is an insulating oil. Noninflammable and nonexplosive liquids have been developed for use as a cooling and insulating medium for electrical equipment. These liquids are used in transformers where their noninflammable and nonexplosive qualities warrant their additional expense. The use of such a liquid is particularly advantageous for transformers installed in buildings, since the transformer may then be installed in general areas without the use of a fireproof vault enclosure. Transformers insulated with such a liquid are designated as askarol-insulated transformers.

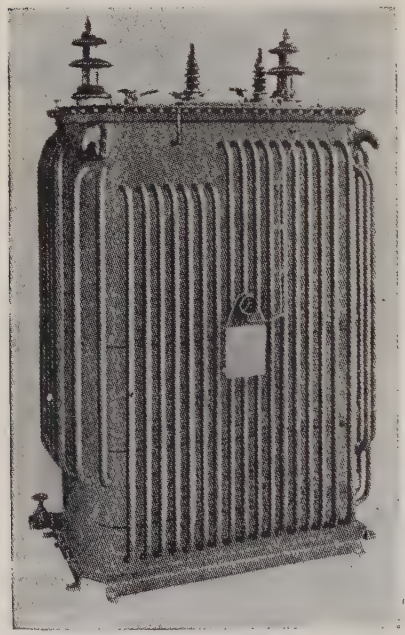


FIG. 10.—Tubular-type tank as used on medium-sized power transformers. (*Maloney Electric Co.*)

Large oil-immersed transformers are frequently cooled by means of a combination of **self-cooling** and **air blast** (Fig. 12). The construction of the transformer is in general the same as for those which are oil immersed and self-cooled, with the addition of a motor-driven blower or blowers mounted integrally with the transformer tank. The blowers provide a forced circulation of air up through the radiators in order to supplement the natural convection air currents. The blower motors are generally automatically controlled by means of a thermostat. When the oil temperature reaches a certain value, the thermostat closes the motor circuit. After the temperature has been reduced to a definite value, the thermostat opens the motor circuit, shutting off the fans.

Oil immersed, water-cooled transformers (Fig. 13) are sometimes employed for large units. Where a plentiful supply of cooling water is available at small cost, they may prove more economical than the self-cooled types. In these transformers a coil of copper or brass pipe is installed near the top of the transformer enclosing tank. Water is circulated through this coil and carries the heat away from the hot oil as it rises in the tank.

In some cases of very large oil-immersed units, a combination of **self- and water-cooling** is employed.

7. The oil used in transformers ("Standard Handbook for Electrical Engineers") performs two important functions. It serves to insulate the various coils from each other and from the core, and it conducts the heat from the coils and core to some cooler surfaces where it is either dissipated in the surrounding air or transferred to some cooling medium. It is evident that the oil should be free from any conducting material, it should be sufficiently thin to circulate rapidly when subjected to differences of temperature at different places, and it should not be ignitable until its temperature is raised to a very high value. Although numerous kinds of oils have been tried in transformers, at the present time mineral oil is used almost exclusively. This oil is obtained by fractional distillation of petroleum unmixed with any other substances and without subsequent chemical treatment. A good grade of transformer oil should show very little evaporation at 100°C., and it should not give off gases at such a rate as to produce an explosive mixture with the surrounding air at a temperature below 180°C. It should not contain moisture, acid, alkali, or sulphur compounds.

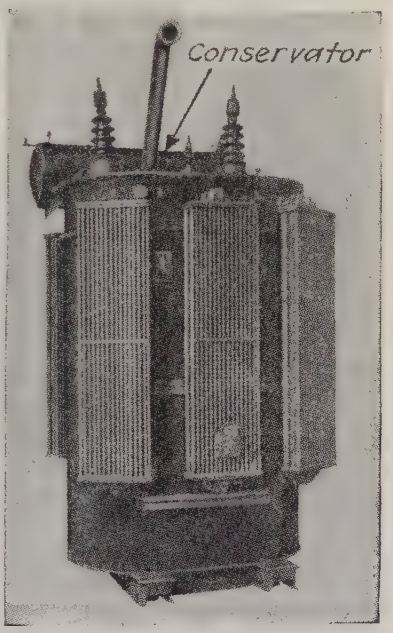


FIG. 11.—Large self-cooled transformers with radiators. Valves are supplied between radiators and tanks. (*Maloney Electric Co.*)

It has been shown by Mr. C. E. Skinner that the deteriorating effect of moisture on the insulating qualities of an oil is very marked; moisture to the extent of 0.06 per cent reduces the dielectric strength of the oil to about 50 per cent of the value when it is free from moisture; but there is very little further decrease in the dielectric strength with an increase in the amount of moisture in the oil.

Dry oil will stand an e.m.f. of 25,000 volts between two 0.5-in. knobs separated 0.15 in. The presence of moisture can be detected by thrusting a red-hot nail in the oil; if the oil "crackles" water is present. Moisture may be removed by raising the temperature slightly above the boiling

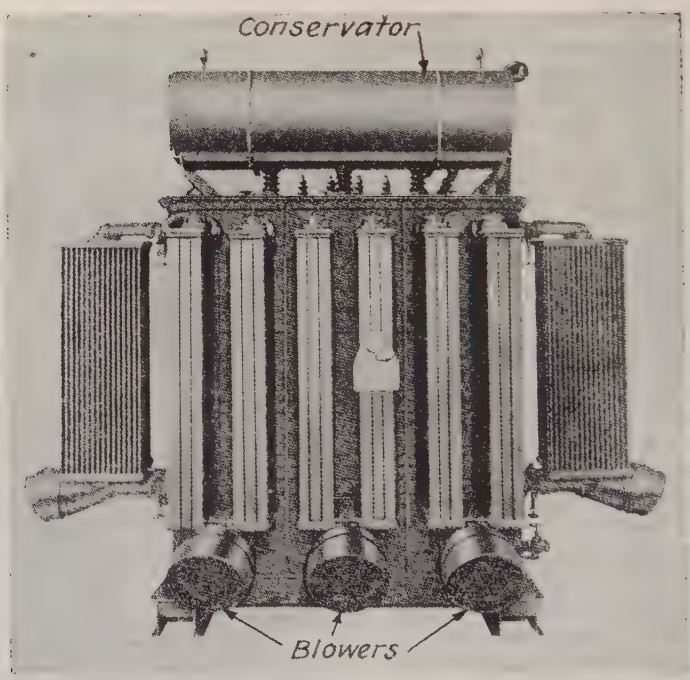


FIG. 12.—Large oil-immersed transformer equipped with radiators and blowers for cooling by combination of self-cooling and air blast.

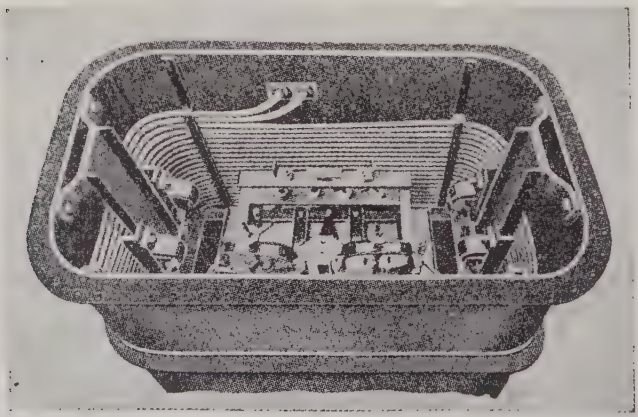


FIG. 13.—View into a water-cooled transformer, showing method of bringing out cooling coils and centering in the tank. (*Maloney Electric Co.*)

point of water, but the time consumed (several days) is excessive. The oil is subsequently passed through a dry-sand filter to remove any traces of lime or other foreign materials.

8. The insulating value of the oil, in oil-immersed transformers, ("Standard Handbook") is depended on very largely to help insulate the transformer; this is done by providing liberal oil ducts between coils and between groups of coils, in addition to the solid insulation. The oil ducts thus serve the double purpose of insulating and cooling the windings.

Since the oil is a very important part of the insulation, every effort is made in modern transformers to preserve both its insulating and cooling qualities. Oxidation and moisture are the chief causes of deterioration. Oil takes into solution about 15 per cent by volume of whatever gas is in contact with it. In the open-type transformer, oil rapidly darkens, owing to the effects of oxygen in solution in the oil and the oxygen in contact with the top surface of the hot oil.

1. Expansion Tank (or Conservator).—One of the first devices used to reduce oxidation was the expansion tank (or conservator) which consisted of a small tank mounted above and connected with the main tank by means of a constricted connection so that the small tank could act as a reservoir to take up the expansion and contraction of the oil due to temperature changes and reduce the oil surface exposed to air.

2. The Inertaire Transformer has the space above the oil in the tank filled with a cushion of inert gas which is mostly nitrogen. The nitrogen atmosphere is initially blown in from a cylinder of compressed nitrogen and is thereafter maintained by passing the in-breathing air through materials which remove the moisture and the oxygen, permitting dry nitrogen to pass into the case. A breathing regulator, which consists of a mercury U-tube with unequal legs, allows in-breathing of nitrogen when the pressure in the case is only slightly below atmospheric, but prevents out-breathing unless the pressure in the case becomes 5 lb. per sq. in. higher than atmospheric pressure. The elimination of oxygen from within the transformer case eliminates the oxidation of the oil and prevents fire and secondary explosion within the case.

9. Insulation between Windings.—The great majority of transformers are constructed with two or more windings which are electrically insulated from each other. In some cases a single winding is employed, parts of the winding functioning both as primary and secondary. These transformers are called autotransformers. They are frequently used when the voltage ratio is small. Autotransformers should never be used for high-voltage ratios, as the low-voltage winding is not insulated from the high-voltage one, so that in case of trouble it would be dangerous to both life and equipment. Refer to Sec. **31** for further discussion.

10. Transformers are built in both single and polyphase units. A polyphase transformer consists of separate, insulated electric windings

for the different phases, wound upon a single core structure, certain portions of which are common to the different phases.

THREE-PHASE TRANSFORMERS ("Standard Handbook").—Although there are numerous possible arrangements of the coils and cores in constructing a polyphase transformer, yet it may be stated that a polyphase transformer generally consists of several one-phase transformers with separate electric circuits but having certain magnetic circuits in common. A three-phase transformer is illustrated in Fig. 14, together with the component one-phase transformer. It will be observed that a three-phase transformer requires three times as much copper as the one-phase component transformer but less than three times as much iron. Thus in comparison with three individual transformers the three-phase unit is somewhat lighter and more efficient. Each component transformer operates as though the others were not present, the flux of one transformer combining with that of an adjacent transformer to produce a resultant flux exactly equal to that of each one alone. Figure 15 shows the interior of a Westinghouse three-phase transformer.

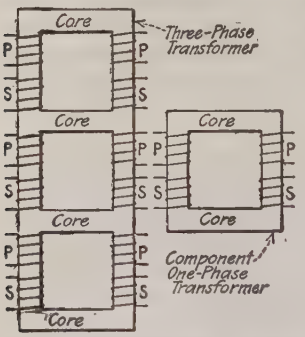


FIG. 14.—Three-phase core-type transformer.

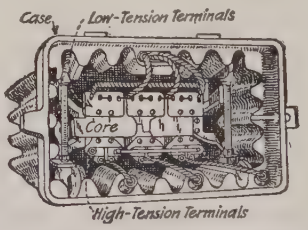


FIG. 15.—Interior view of a Westinghouse three-phase transformer.

11. Application of Three-phase Transformers (A. D. Fishel).—For central stations of medium sizes, three-phase transformers are rarely superior to single phase except where the large sizes can be applied, in which cases the transformers are normally installed in substations or central stations. The chief reason for this is the nonflexibility of a three-phase transformer. It is usually purchased for a particular size and type of load, and, if that load should be changed, the transformer, representing a comparatively heavy investment, remains on the hands af the central station, whereas a single-phase transformer of one-third the size could usually be adapted for some other service.

This feature becomes of less importance as the central station increases its size, and three-phase transformers for purely power service are now being used by a considerable number of the large central stations of this country. The three-phase transformer costs less to install, and the

connections are simpler, points that are of importance in connection with outdoor installations. The fact that a failure of a three-phase transformer would interrupt service more than the failure of one single-phase transformer in a bank of three is of little importance because of the comparatively few failures of modern transformers. On the other hand, especially for 2,200-volt service, the single-phase transformer has been carried to a high degree of perfection and is manufactured in much larger quantities, so that better performance is usual and, in some cases, initial cost is lower. Three-phase distribution transformers are used extensively in underground city network service on account of the smaller space required by them in the manhole, their higher efficiency, and their lower initial cost. For overhead service for pole or platform mounting, three single-phase units are more common on account of the ease of handling and mounting the smaller sized units.

12. Methods of Mounting.—Transformers are constructed with different types of metal enclosing structures in order to meet the requirements of different conditions of installation. One type of enclosure (Figs. 8 and 22) is designed **with lugs for the attachment of hanger irons for mounting on poles** for use in overhead distribution work. Another type of enclosure, called the **platform type** (Figs. 10, 11, and 12), is suitable for installations where the transformer stands upon its own base. It may be mounted on any flat horizontal surface having sufficient mechanical strength, such as a floor or a platform between poles. **Subway transformers** (Fig. 9) have watertight tanks which are designed primarily for underground installations where the transformer may be completely submerged in water. **Vault transformers** also have watertight enclosures so that they will not be injured by total submersion, but they are not designed to operate satisfactorily under such conditions. The vault transformers are intended for operation in underground vaults where dampness is prevalent and where occasional submersion might occur but where the transformer would not be required to operate for any considerable length of time while submerged. Small transformers for power and special application as listed in Sec. **5**(6*c* to 6*j*) are designed with special types of mounting in order to meet the requirements of installation for these types of service.

13. Purpose of Transformers.—Transformers may be classified as given in Sec. **5**(5) according to the purpose of transformation for which they are employed.

The function of a **constant-potential** transformer is to change the voltage of a system. It is designed to operate with its primary connected across a constant-potential supply and to provide a secondary voltage which is substantially constant from no load to full load. It is the ordinary common type of transformer. The currents of both primary and secondary vary with the load supplied by the transformer. A **varying-potential** transformer is also intended for changing the voltage of a system

but is so designed that when operated with its primary connected to a constant-potential supply the secondary voltage will vary widely with the load. Such transformers are necessary for the auxiliary transformers for the operation of many gaseous-discharge lamps.

A **current** transformer is one which is designed for changing the current of a system. The primary winding of such a transformer is connected in series with the circuit of which it is desired to change the current. The voltage of both primary and secondary will change with the value of the current of the system. Such transformers are used for instrument transformers and in some series street-lighting installations. **Constant-current** transformers are designed for supplying a constant value of secondary current regardless of the load on the transformer. The primary is connected to a constant-potential source. The secondary voltage varies proportionally with the load, while the secondary current remains constant. The primary current and kilovolt-amperes will be constant for all loads, but the kilowatt input and power factor will vary with the load.

14. The most important application of constant-potential transformers is for raising the voltage of an electric transmission circuit so that energy can be transmitted for considerable distances with small voltage drop and small energy loss, and then lowering the voltage for safe usage by motors, lights, and appliances.

15. The Theory of Operation of the Constant-potential Transformer (see Fig. 1).—It has been shown in Div. 1 that turns of wire wound on an iron core have self-induction. When an alternating voltage is applied to such turns a current flows through them that generates a countervoltage or e.m.f. that opposes the applied voltage. From formulas, the transformer designer can compute just how many turns are necessary for a transformer of a given size so that it will generate a countervoltage equal to the applied voltage. So, in designing the primary winding of the transformer of Fig. 1, the designer would select such a number of turns for the primary winding that the countervoltage generated by it would be nearly 2,200 volts. Hence, when the primary winding is connected to a 2,200-volt circuit, it generates a countervoltage of practically 2,200, and no appreciable current flows. A small current, the exciting current, just enough to magnetize the core, does flow, but it is so small that it can be disregarded in this discussion.

Since the primary and secondary windings are on the same core, the magnetic flux generated by the magnetizing or exciting current flowing in the primary winding also cuts the turns of the secondary winding and generates an e.m.f. in them. This e.m.f. will be, in accordance with a well-known law, opposite in direction to that impressed on the primary. If the secondary circuit is open, no current can flow in it, but if it is closed, a certain current, proportional to the impedance of the secondary circuit,

will flow. This current, because of the direction of the e.m.f. generated in the secondary, will be in such a direction that the magnetic flux produced in the core by it will oppose the flux due to the primary winding. It will therefore decrease the effective or resultant flux in the core by a small amount which will decrease the counter-e.m.f. of the primary winding and permit more current to flow into the primary winding. As noted elsewhere, the ratio of the number of turns in the primary winding to the number of turns in the secondary winding determines the ratio of the primary to the secondary voltage.

If the voltage impressed on the transformer is maintained constant the voltage of the secondary will be nearly constant also. When more current flows in the secondary there will be a corresponding increase in primary current. As the load on a transformer increases, the impressed voltage remaining constant, there is actually a slight drop from the no-load voltage of the secondary, due to certain inherent characteristics of the transformer, but in a properly designed device this drop will be very small. Although the construction and elementary theory of the transformer are very simple, a theoretical explanation of all the phenomena involved in its operation is very complicated. Only the principal features have been described. Some minor, though very important, considerations that would complicate the explanation have not been treated.

16. Transformer Ratios.—The voltage ratio of a constant-potential transformer, *i.e.*, the ratio of primary to secondary voltage, depends primarily upon the ratio of the primary to the secondary turns. The voltage ratio will vary slightly with amount and power factor of load. For general work the voltage ratio can be taken equal to the turn ratio of the windings.

The current ratio of a constant-potential transformer will be approximately equal to the inverse ratio of the turns in the two windings. For example, for transforming or "stepping down" from 2,400 volts to 120 volts the ratio of the turns in the windings will be 20:1. The currents in the primary and the secondary windings will be, very closely, inversely proportional to the ratio of the primary and secondary voltages, because, disregarding the small losses of transformation, the power put into a transformer will equal the power delivered by it. For example, considering a transformer with windings having a ratio of 20:1, if its secondary winding delivers 100 amp. at 50 volts the input to its primary winding must receive almost exactly 5 amp. at 1,000 volts. The input and output are each (practically) equal, and each would equal (almost exactly) 5,000 watts.

17. The regulation of a transformer is the change in secondary voltage from no load to full load. It is generally expressed as a percentage of the full-load secondary voltage.

$$\text{Per cent regulation} = \frac{\text{no-load secondary voltage} - \text{full-load secondary voltage}}{\text{full-load secondary voltage}} \times 100 \quad (1)$$

The regulation depends upon the design of the transformer and the power factor of the load. Although with a noninductive load such as incandescent lamps the regulation of transformers is within about 3 per cent, with an inductive load the drop in potential between no load and full load increases to possibly about 5 per cent. If the motor load is large and fluctuating, and close lamp regulation is important, it is desirable to use separate transformers for the motors.

18. The efficiency of a transformer is, as with any other device, the ratio of the output to input or, in other words, the ratio of the output to the output plus the losses. As a formula it may be expressed thus:

$$\text{Efficiency} = \frac{\text{output}}{\text{input}} = \frac{\text{output}}{\text{output} + \text{copper loss} + \text{iron loss}} \quad (2)$$

Average efficiencies of transformers are given in Secs. **42** to **56.**

19. The copper loss of a transformer is determined by the resistances of the high-tension and low-tension windings and of the leads. It is equal to the sum of the watts, I^2R losses in these components at the load for which it is desired to compute the efficiency.

20. The iron loss of a transformer is equal to the sum of the losses in the iron core. These losses consist of eddy- or Foucault-current losses and hysteresis losses. Eddy-current losses are due to currents generated by the alternating flux circulating within each lamination composing the core, and they are minimized by using thin laminations and by insulating adjacent laminations with insulating varnish. Hysteresis losses are due to the power required to reverse the magnetism of the iron core at each alternation and are determined by the amount and the grade of iron used for the laminations for the core.

21. Transformer Ratings.—Transformers are rated at their kilovolt-ampere (kva.) outputs. If the load to be supplied by a transformer is at 100 per cent power factor the kilowatt (kw.) output will be the same as the kilovolt-ampere output. If the load has a lesser power factor, the kilowatt output will be less than the kilovolt-ampere output proportionally as the load power factor is less than 100 per cent.

Example.—A transformer having a full-load rating of 100 kva. will safely carry 100 kw. if the 100 kw. is at 100 per cent power factor, or 90 kw. at 90 per cent power factor, or 80 kw. at 80 per cent power factor.

Transformers are generally rated on the kilovolt-ampere load which the transformer can safely carry continuously without exceeding a

temperature rise of 55°C. when maintaining rated secondary voltage at rated frequency and when operating with an ambient temperature of 40°C. (Ambient temperature is the temperature of the surrounding atmosphere.) The actual temperature of any part of the transformer is the sum of the temperature rise of that part plus the ambient temperature.

The usual service conditions under which a transformer should be able to carry its rated load are:

1. At rated secondary voltage or not in excess of 105 per cent of rated value.
2. At rated frequency.
3. Temperature of the surrounding cooling air at no time exceeding 40°C. and average temperature of the surrounding cooling air during any 24-hr. period not exceeding 30°C.
4. Altitude not in excess of 3,300 ft. when the cooling medium is air.
5. If water cooled, the average temperature of the cooling water during any 24-hr. period does not exceed 25°C.

GUIDE FOR LOADING OIL-IMMERSED DISTRIBUTION AND POWER TRANSFORMERS

(Prepared by the American Standards Association)

22. Scope.—These guides cover general recommendations for loading oil-immersed transformers (with the exception of forced-oil-cooled transformers) including those with synthetic or noninflammable liquid. Reference should be made to the manufacturer for more specific recommendations, particularly for large or important transformers.[1] No recommendations for loading transformers of the air-blast type have been established.

23. General.—The rated output of a transformer is fixed by its nameplate temperature rise, measured under specified test conditions. The output which it can deliver in service without causing undue deterioration of the insulation may be more or less than the rated output, depending upon the attendant operating conditions.

Since the evaluation of the cumulative effects of temperature and time in causing deterioration of transformer insulation is not thoroughly established, it is not possible to predict definitely the length of life of a transformer even under constant or closely controlled conditions, much less under widely varying service conditions. Experience and tests, however, indicate that the rate of deterioration of transformer insulation approximately doubles for each 8°C. increase in temperature. Years of experience

[1] The transformers referred to in these guides are both old and new self-cooled designs and modern water-cooled designs (built since 1928). The loading of older water-cooled transformers should be based upon information furnished by the manufacturers, or tests made on the individual units.

have shown that a transformer rated in accordance with the Standards will generally have a reasonably long life under usual service conditions.

Since the actual temperature is the sum of the ambient temperature and the temperature rise, it is apparent that the ambient temperature very largely determines the load which can reasonably be carried in service. Ambient temperatures and service conditions have been established in the following paragraphs to serve as a guide for the loading of transformers in service.

24. Transformers Equipped with Means for Determining the Winding Temperature.—When temperature indicators for determining the winding temperature under operating conditions are available, the load should be controlled to limit the winding temperature to safe values.

25. a. Temperature Maintained Continuously.—See the last column of the following table.

b. Temperature Due to Recurrent Short-time Overload Operation.—A recurrent short-time overload is one of limited duration that is imposed in accordance with a known schedule; it is regarded as occasional and not occurring oftener than approximately once every 24 hr. An emergency short-time overload is an unexpected overload of limited duration; it is to be regarded as an infrequent occurrence.

The following temperatures may be permitted for such overloads:

For an indicator marked in terms of	Emergency			Recurrent		
	Time			Time in any 24-hr. period		
	2 hr.	8 hr.	24 hr.	2 hr.	8 hr.	24 hr.
	Temperature, deg. C					
Hottest-spot temperature	115	110	105	110	105	95
Embedded-detector temperature	110	105	100	105	100	90
Average copper temperature (by resistance)	105	100	95	100	95	85

26. Transformers Not Equipped with Means for Determining the Winding Temperature but with Oil-temperature Indicator.—On account of the large differences between the winding and oil temperatures of various designs under full-load conditions and the time lag between windings and oil under varying load conditions, it is not possible to use oil temperature alone as an accurate guide in loading transformers. When it is necessary to use the oil temperature as an accurate guide, it should be used only in combination with a curve or tabulation (furnished by the

manufacturer) giving permissible oil temperatures for various loads for that particular transformer.

The values of top-oil temperature versus loads given below are conservative, being based upon (1) a difference of 25°C. between winding hottest-spot and oil temperatures at 100 per cent self-cooled or water-cooled rating, (2) a difference of 30°C. between winding hottest-spot and oil temperatures at 100 per cent forced-air-cooled rating, and (3) this difference varying as the load raised to the 1.6 power.

The values given in the tabulation below may be used as a rough guide for loading transformers.

a. Temperature Maintained Continuously

Permissible load, per cent		Top-oil temperature limits, deg. C.	
Self-cooled or water cooled	Forced-air cooled	Self-cooled	Forced-air cooled or water cooled[a]
100	100	70	65
112	110	65	60
123	120	60	55
134	129	55	50
144	138	50	45

[a] The oil-temperature limits for both water-cooled and forced-air-cooled transformers are 5 deg. lower than for self-cooled transformers due (1) to the ambient for water-cooled transformers being 25°C. instead of 30°C. as for self-cooled transformers, and (2) to the oil rise of forced-air-cooled transformers being approximately 5 deg. lower than for self-cooled transformers at rated load.

b. Recurrent Short-time Overloads

Permissible load, per cent		Top-oil temperature limits, deg. C.					
		Self-cooled			Forced-air cooled or water cooled		
Self- or water cooled	Forced-air cooled	2 hr.	8 hr.	24 hr.	2 hr.	8 hr.	24 hr.
100	100	85	80	70	80	75	65
112	110	80	75	65	75	70	60
123	120	75	70	60	70	65	55
134	129	70	65	55	65	60	50
144	138	65	60	50	60	55	45

c. Emergency Short-time Overloads

Permissible load, per cent		Top-oil temperature limits, deg. C.					
		Self-cooled			Forced-air cooled or water cooled		
Self- or water cooled	Forced-air cooled	2 hr.	8 hr.	24 hr.	2 hr.	8 hr.	24 hr.
100	100	90	85	80	85	80	75
112	110	85	80	75	80	75	70
123	120	80	75	70	75	70	65
134	129	75	70	65	70	65	60
144	138	70	65	60	65	60	55

27. Transformers Not Equipped with Means for Determining the Temperature.—For transformers not equipped with temperature indicators that indicate the temperature of the transformer under operating conditions, the load should be limited to values which will not cause excessive temperatures. The following values have been established as reasonable for transformers of usual design having a winding temperature rise (by resistance) of 55°C. at rated load.

a. Rated Load Maintained Continuously.—A transformer may be operated continuously at rated load with service conditions as given in Sec. **21.**

b. Continuous Load Limits for Daily Average Cooling-medium Temperatures of Higher Values.—When the average temperature of the cooling air during any 24-hr. period exceeds 30°C., it is recommended that the load be reduced 2 per cent below rated kilovolt-amperes for each degree Centigrade that the average temperature of the cooling air exceeds 30°C.

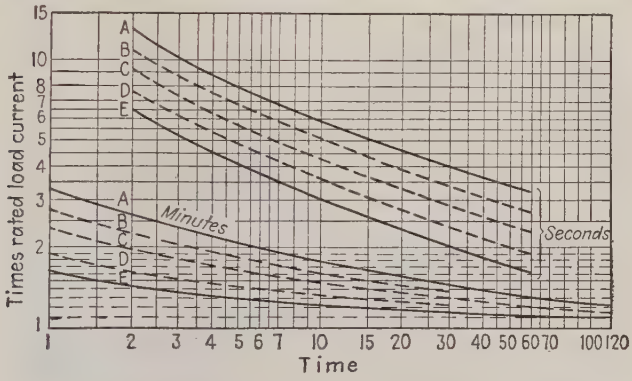
For water-cooled transformers the load should be reduced 2 per cent below rated kilovolt-amperes for each degree Centigrade that the average cooling water temperature exceeds 25°C.

The use of transformers in cooling air exceeding 50°C. or with cooling water exceeding 35°C. should be given special consideration.

c. Continuous Load Limits for Daily Average Cooling-medium Temperatures of Lower Values.—(1) Oil-immersed, self-cooled transformers may be loaded continuously 1 per cent above rated kilovolt-amperes for each degree centigrade that the daily average temperature of the cooling medium (air) is below 30°C.

(2) An oil-immersed, self-cooled, forced-air-cooled transformer may be loaded continuously above its forced-air-cooled rated kilovolt-amperes 1 per cent of its self-cooled rated kilovolt-amperes for each degree centi-

grade that the daily average temperature of the cooling medium (air) is below 30°C. For example, if the self-cooled rating is 10,000 kva. and the forced-air-cooled rating is 13,333 kva., the permissible continuous loading with a daily average air temperature of 0°C. would be 13,333 + (0.30 × 10,000) = 16,333 kva. with forced-air cooling. This increase amounts



Curve	Load conditions	Curves based on times rated load current		
		Time	*A*	*E*
A	Following no load (excitation only)	2 sec.	13.00	6.50
B	Following 50 per cent load	5 sec.	8.00	4.00
C	Following 75 per cent load	10 sec.	6.00	3.00
D	Following 90 per cent load	30 sec.	4.00	2.00
E	Following full load	60 sec.	3.25	1.60
		5 min.	2.10	1.30
		30 min.	1.45	1.15
		120 min.	1.20	1.10

NOTE: For forced-air-cooled oil-immersed transformers use 75 per cent of the indicated increase over rated load current shown by these curves.
See Fig. 18 for small transformers.

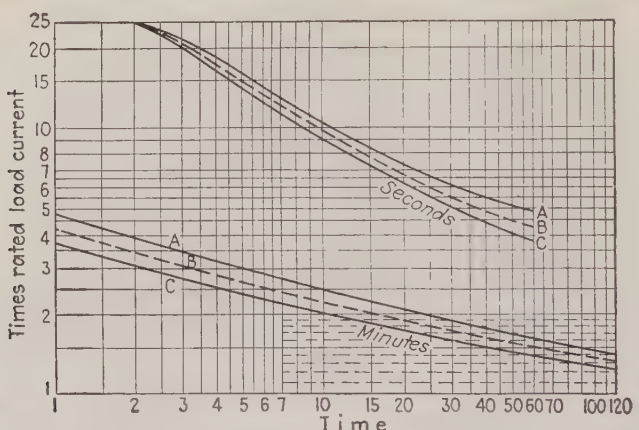
FIG. 16.—Recurrent short-time overloads for oil-immersed transformers. Self-cooled with 30°C. cooling air, or water-cooled with 25°C. cooling water.

to 0.75 per cent of its forced-air-cooled rating for each degree Centigrade that the ambient is below 30°C.

(3) Oil-immersed, water-cooled transformers may be loaded continuously 1 per cent above rated kilovolt-amperes for each degree centigrade that the daily average temperature of the cooling medium (water) is below 25°C.

(4) Continuous loads greater than 130 per cent of rated kilovolt-amperes for self-cooled transformers, even though the temperature of the air is lower than 0°C., and continuous loads greater than 125 per cent of rated kilovolt-amperes for water-cooled transformers are not recommended.

d. Recurrent Short-time Overloads for Self-cooled and Water-cooled, Oil-immersed Transformers.—Recurrent short-time overloads (see Sec. **25, a**) may be applied to self-cooled, oil-immersed transformers with daily average cooling air at 30°C. or to water-cooled, oil-immersed transformers with daily average cooling water at 25°C., in accordance



Curve	Load conditions	Curves based on times rated load current		
		Time	*A*	*C*
A	Following no load (excitation only)	2 sec.	25.0	25.00
B	Following 75 per cent load	5 sec.	16.0	14.00
C	Following full load	10 sec.	10.5	9.00
		30 sec.	6.0	5.00
		60 sec.	4.7	3.70
		5 min.	3.0	2.40
		30 min.	1.9	1.60
		120 min.	1.4	1.25

NOTE: For forced-air-cooled oil-immersed transformers use 75 per cent of the indicated increase over rated load current shown by these curves.
See Fig. 18 for small transformers.

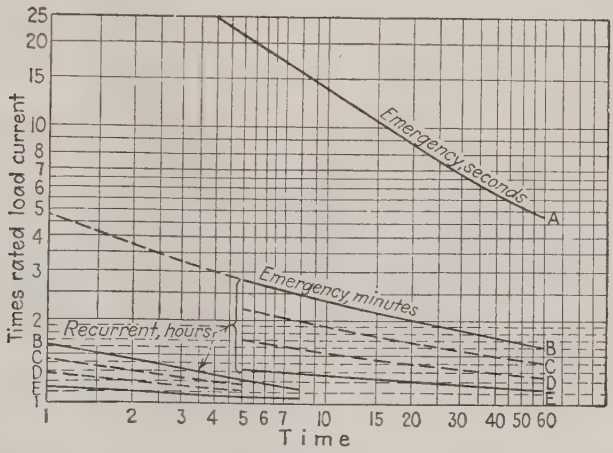
FIG. 17.—Emergency short-time overloads for oil-immersed transformers. Self-cooled with 30°C. cooling air, or water-cooled with 25°C. cooling-water.

with the curves given in Fig. 16. (Exception: For network transformers rated 500 kva. and below and for other transformers rated 100 kva. and below and rated below 15,000 volts, recurrent short-time overloads may be applied in accordance with the curve given in Fig. 18.)

e. Emergency Short-time Overloads for Self-cooled and Water-cooled, Oil-immersed Transformers.—Emergency short-time overloads (see Sec. **25, b**) may be applied to self-cooled, oil-immersed transformers with daily average cooling air at 30°C. or to water-cooled, oil-immersed

transformers with daily average cooling water at 25°C., in accordance with the curves given in Fig. 17.

For network transformers rated 500 kva. and below and for other transformers rated 100 kva. and below and rated below 15,000 volts,



Curve	Load conditions	Curves based on times rated load current			
		Time	*A*	*B*	*E*
A	Emergency, following full load	4 sec.	25		
B	Recurrent, following no load	10 sec.	13.7		
C	Recurrent, following 50 per cent load	30 sec.	6.7		
D	Recurrent, following 75 per cent load	60 sec.	4.75		
E	Recurrent, following 90 per cent load	5 min.	2.8	2.8	1.32
		30 min.	.....	1.85	1.18
		60 min.	.....	1.6	1.11
		2 hr.	.....	1.4	1.08
		5 hr.	.....	1.2	1.05

These curves apply to transformers 100 kva. and smaller, below 15,000 volts, and for etwork transformers 500 kva. and smaller.

NOTE: For forced-air-cooled oil-immersed transformers use 75 per cent of the increase ver rated load current shown by these curves.

IG. 18.—Short-time overloads for oil-immersed transformers. Self-cooled with 30°C. Cooling air or water-cooled with 25°C. cooling water.

mergency short-time overloads following full load may be applied in ccordance with the curve given in Fig. 18.

f. Recurrent and Emergency Overload with Cooling-air Temperatures ther Than 30°C. or Cooling-water Temperatures Other Than 25°C.— hort-time loads (shown in Figs. 16, 17, and 18) may be increased by per cent of the continuous water-cooled rating for each degree Centi- rade that the daily average cooling water temperature is below 25°C

Short-time loads should be reduced 2 per cent of the continuous self-cooled rating below the recommended load for each degree Centigrade that the daily average temperature of the cooling air exceeds 30°C.

Short-time loads should be reduced 2 per cent of the continuous water-cooled rating below the recommended load for each degree Centigrade that the daily average temperature of the cooling water exceeds 25°C.

The use of self-cooled, oil-immersed transformers in cooling air exceeding 50°C. or of water-cooled, oil-immersed transformers with cooling water exceeding 35°C. should be given special consideration.

28. Increased Periods of Operation of Pole-type Constant-current Transformers for Ambient Temperatures Lower Than Normal.—Since pole-type, constant-current transformers operate outdoors at night when the ambient temperature is comparatively low, it is often desirable to take advantage of the longer period of operation within the limiting temperature rise which is made possible by an ambient temperature lower than normal. For these reasons, the time of operation of a pole-type, constant-current transformer may be increased as the average ambient temperature decreases, as follows:

Average Ambient Temperature, Deg. C.	Period of Operation, Hr.
30	8
25	10
20	12
15	14
10	16

29. Capacities of Transformers for Induction Motors
(General Electric Co.)

Size of motor, hp.	Kva. per transformer		
	Two single-phase transformers	Three single-phase transformers	One three-phase transformer
1	0.6	0.6	
2	1.5	1.0	2.0
3	2.0	1.5	3.0
5	3.0	2.0	5.0
7½	4.0	3.0	7.5
10	5.0	4.0	10.0
15	7.5	5.0	15.0
20	10.0	7.5	20.0
30	15.0	10.0	30.0
50	25.0	15.0	50.0
75	40.0	25.0	75.0
100	50.0	30.0	100.0

30. Capacities of Transformers for Operating Motors (General Electric Co.).—For the larger motors the capacity of the transformers in kilovolt-amperes should equal the output of the motor in horsepower. Thus a 50-hp. motor requires 50 kva. in transformers. Small motors should be supplied with a somewhat larger transformer capacity, especially if, as is desirable, they are expected to run most of the time near full-load, or even at slight overload. Transformers of less capacity than those noted in Table 29 should not be used even when a motor is to be run at only partial load.

31. The Autotransformer ("Standard Handbook").—The most efficient and effective method of operating a stationary transformer

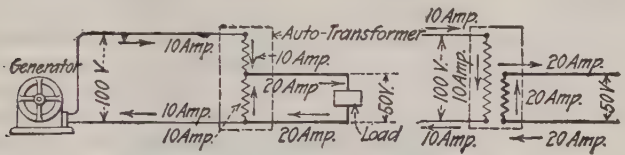


FIG. 19. FIG. 20.

FIG. 19.—Electric circuits of a 1-kw., single-phase autotransformer.
FIG. 20.—Electric circuits of a 1-kw., single-phase, two-coil transformer equivalent to the autotransformer of Fig. 19.

(when the ratio of transformation is not too large) is as an autotransformer, *i.e.*, with certain portions of the windings used simultaneously as the primary and the secondary circuit. The electrical circuits of a one-phase autotransformer (sometimes called a compensator or a balance coil) are indicated in Fig. 19. The autotransformer has only one coil, a certain portion of which is used for both the high-tension and the low-tension winding. The number of turns of this coil is the same as would be required if it were used exclusively for the high-tension winding and a separate additional coil were used for the low-tension winding. Moreover, when the ratio of transformation is 2:1 or 1:2, the amount of copper in the one coil is exactly the same whether it is used as an autotransformer or as a high-tension coil of a two-coil transformer of the same rating. Not only is less copper required for an autotransformer than for a two-coil transformer, but less iron is needed to surround the copper.

Referring again to Fig. 19, it is to be noted that the one-coil transformer is designed for 10 amp. throughout and for a total e.m.f. of 100 volts. The voltage per turn is uniform throughout, so that to obtain 50 volts it is necessary merely to select any two points on the continuous winding such that one-half of the total number of turns is included between them. The load current of 20 amp. (required for 1,000 watts at 50 volts) is opposed by the superposed 10 amp. of primary current, so that even in this section of the coil the resultant current is only 10 amp. If an ordinary two-coil transformer had been used, the circuits would have been as noted in Fig. 20, while the required constructive material

would have been approximately as indicated in Fig. 21, I. So far as concerns its constructive material, a 1-kw., 2:1 ratio autotransformer is the equivalent of a 1:1 ratio, 0.5-kw., two-coil transformer as shown in Fig. 21, II. The latter transformer requires about 14 lb. of copper and 28 lb. of iron as compared with about 22 lb. of copper and 34 lb. of iron for the transformer of Fig. 21, I. Moreover, the losses of the autotransformer are correspondingly less than those of a two-coil transformer.

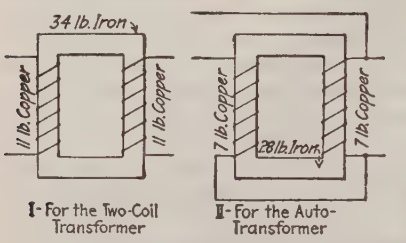


FIG. 21.—Comparison of constructive material required for a transformer and for an autotransformer.

32. Constant-potential transformers for the transformation of a large amount of power, more than 500 kva., are called power transformers. Transformers for general constant-potential power transformation, whose rating is 500 kva. or less, are called distribution transformers. All the methods of cooling except air immersed, self-cooled, are employed for power transformers. The choice depends upon which will result in the best over-all economy including first cost, operating expense, and space occupied. Distribution transformers are always liquid immersed, self-cooled. Power and distribution transformers are normally of the standard type with the windings insulated from each other, although those with autotransformer construction can be obtained for special applications where the voltage ratio is small. Power transformers are always of the platform type. Distribution transformers are made with tanks for pole and platform mounting, and with tanks of the subway and vault types. The tanks of the platform type of transformers of 50 kva. capacity and smaller are equipped with lugs or brackets (Fig. 22) for direct pole mounting or for the attachment of hanger irons for cross-arm pole mounting.

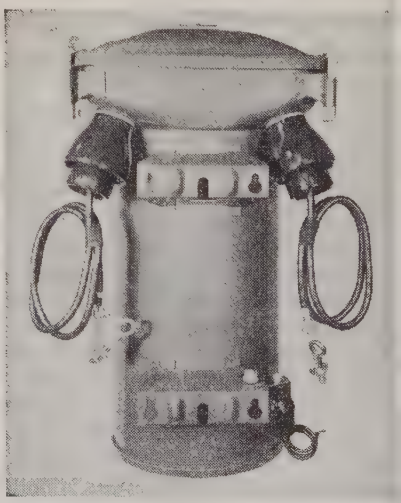


FIG. 22.—Distribution transformer for pole mounting. (*American Transformer Co.*)

33. Network transformers are distribution transformers specially constructed and equipped with attached auxiliaries such as junction boxes and switches for disconnecting and grounding the high-voltage cable in order to meet the requirements of transformers for supplying low-voltage networks.

34. Self-protected distribution transformers are equipped with lightning and overload protective equipment built integrally with the

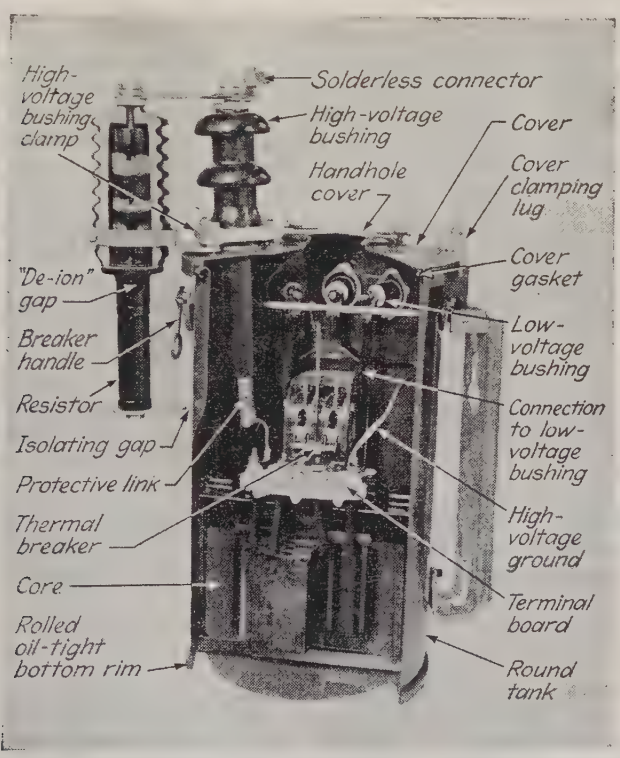


FIG. 23.—Sectional view of CSP transformer. (*Westinghouse Electric & Manufacturing Co.*)

transformers. They are made in two types: completely self-protecting (CSP), *i.e.*, having both overload and lightning protection, and with only surge protection (SP). The connections of the lightning protective equipment can be made in different ways in order to satisfy any desired grounding practice. A sectional view of such a CSP transformer is shown in Fig. 23.

35. Voltage Taps.—It is frequently desirable on transformers to obtain a voltage ratio which is slightly different from the standard ratio obtained with the complete winding. Most transformers are provided with two 5 per cent taps on the high-voltage winding for this purpose. The taps are for reduced voltage and allow the rated secondary voltage to be obtained when the supply voltage is below the rated value. Many transformers are equipped with a ratio adjuster (Fig. 24). The ratio adjuster provides a means of changing taps on the transformer by simply turning an operating handle without having to take down and remake connections. The diagram of connections of a ratio adjuster is shown in Fig. 25. The transformer of the illustration is provided with two primary coils instead of one as would be the more general practice. The transformer should be disconnected from the line before the taps are changed with the ratio adjuster, as the device is not intended for operation under load.

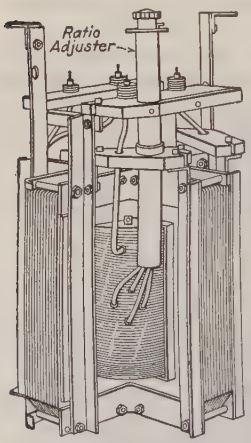
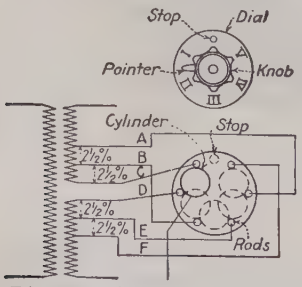


FIG. 24.—Core and coils for a 6,600-volt distribution transformer showing ratio adjuster. (*General Electric Co.*)

The standard taps for distribution transformers are given in Sec. **36.** A rated-kilovolt-ampere tap is a tap through which the transformer can deliver its rated kilovolt-ampere output without exceeding its rated temperature rise. A reduced-kilovolt-ampere tap is a tap through which the transformer can deliver only a kilovolt-ampere output less than its rated value without exceeding its rated temperature rise.



Position	Connecting	% of Winding
I	C to D	100
II	B to D	97.5
III	B to E	95
IV	A to E	92.5
V	A to F	90

FIG. 25.—Diagram of ratio adjuster connections to transformer with four 2½ per cent taps. (*General Electric Co.*)

Large power transformers frequently are equipped with load-ratio control equipment by means of which the connections to taps of the transformer can be changed under load.

36. Preferred Ratings of Transformers

Single-phase, 500 kva. and below. Used primarily to step down from a transmission or distribution voltage to a utilization voltage

Rated circuit voltage	Max. and min. rated kva.	High voltage winding				Low voltage winding, rated voltage			
		Rated voltage	Rated kva. tap		Reduced kva. tap				
480	1.5–100	480	456	432	.....	120/240			
600	1.5–100	600	570	540	.....	120/240			
2,400 and	1.5– 50	2,400/4,160Y	.....	.....	.....	120/240	240/480	600	
4,160	75–500	2,400/4,160Y	2,280	2,160	.....	120/240	240/480	600	
4,800	1.5–100	2,400/4,800	.....	.....	.....	120/240	240/480	600	
	150–500	2,400/4,800	2,280	2,160	.....	120/240	240/480	600	
7,200 and	1.5–500	7,200/12,470Y	6,875	6,545	6,220	120/240	240/480	600	
12,000	5–500	7,200/12,470Y	6,840	6,480	.....	.....	.....	...	2,400
	3–500	12,000	11,400	10,800	.....	120/240	240/480	600	
	5–500	12,000	11,400	10,800	.....	.....	.....	...	2,400/4,160Y
13,800	1.5–500	7,620/13,200Y	7,240	6,860	.....	120/240	240/480	600	
	5–500	7,620/13,200Y	7,240	6,860	.....	.....	.....	...	2,400
	3–500	13,200	12,540	11,880	.....	120/240	240/480	600	
	5–500	13,200	12,540	11,880	.....	.....	.....	...	2,400/4,160Y
23,000	10–500	22,000	20,900	19,800	.....	120/240	240/480	600	2,400/4,160Y
	10–500	12,700/22,000Y	12,070	11,430	.....	120/240	240/480	600	2,400
34,500	15–500	33,000	31,350	29,700	.....	120/240	240/480	600	2,400/4,160Y
	15–500	19,050/33,000Y	18,100	17,150	.....	120/240	240/480	600	2,400
46,000	25–500	44,000	41,800	39,600	.....	120/240	240/480	600	2,400/4,160Y
	25–500	25,400/44,000Y	24,140	22,860	.....	120/240	240/480	600	2,400
69,000	50–500	66,000	62,700	59,400	.....	120/240	240/480	600	2,400/4,160Y
	50–500	38,100/66,000Y	36,200	34,290	.....	120/240	240/480	600	2,400

NOTES: 1. Transformers rated at 200 kva. and below, having low-voltage ratings of 120/240 volts, are suitable for series-multiple or three-wire service; transformers rated at 250 kva., 333 kva., or 500 kva. are suitable for series or three-wire service only.

2. Transformers having low-voltage ratings of 240/480 volts are suitable for series or multiple service only.

3. Transformers for operating in parallel with existing transformers or for use on existing systems, but requiring different voltages and taps than given in the tables, shall have the same status as the ratings of the same voltage class, provided that number and voltage range of the taps is not exceeded.

4. Standard ratings are under review by a joint committee of the Edison Electric Institute and the National Electrical Manufacturers' Association.

37. Preferred Ratings for Transformers

Three-phase, 450 kva. and below. Used primarily to step down from a transmission or distribution voltage to a utilization voltage

Rated circuit voltage	Max. and min. rated kva.	High voltage winding			Low voltage winding, rated voltage			
		Rated voltage	Rated kva. taps					
2,400 and	10–150	2,400/4,160Y	.....	.....	240/480	600		
4,160	200–450	2,400/4,160Y	2,280	2,160	240/480	600		
4,800	10–450	4,800Y	4,560	4,320	240/480	600		
7,200	10–450	7,200Y	6,840	6,480	240/480	600		
	10–450	7,200Y	6,840	6,480	.....	...	2,400	
	10–450	7,200Δ	6,840	6,480	.....	...	2,400/4,160Y	
12,000	10–450	12,000	11,400	10,800	240/480	600		
	10–450	12,000	11,400	10,800	.....	...	2,400	
	10–450	12,000	11,400	10,800	.....	...	2,400/4,160Y	
13,800	15–450	13,200Y	12,540	11,880	240/480	600	2,400	
	15–450	13,200Δ	12,540	11,880	.....	...	2,400/4,160Y	
23,000	25–450	22,000Y	20,900	19,800	240/480	600	2,400	
	25–450	22,000Δ	20,900	19,800	.....	...	2,400/4,160Y	
34,500	50–450	33,000Y	31,350	29,700	240/480	600	2,400	
	50–450	33,000Δ	31,350	29,700	.....	...	2,400/4,160Y	
46,000	50–450	44,000Y	41,800	39,600	240/480	600	2,400	
	50–450	44,000Δ	41,800	39,600	.....	...	2,400/4,160Y	
69,000	150–450	66,000Y	62,700	59,400	240/480	600	2,400	
	150–450	66,000Δ	62,700	59,400	.....	...	2,400/4,160Y	

NOTES: 1. Transformers having low-voltage ratings of 240/480 are suitable for series or multiple service only.

2. Transformers for operating in parallel with existing transformers or for use on existing system, but requiring different voltages and taps than given in the tables, shall have the same status as the standard ratings of the same voltage class, provided that number and voltage range of the taps is not exceeded.

3. Standard ratings are under review by a joint committee of the Edison Electric Institute and the National Electrical Manufacturers' Association.

38. Preferred Ratings of Transformers

Kva. ratings

Single-phase				Three-phase			
1½	75	833	6,667	10	200	2,000	12,000
3	100	1,000	8,333	15	300	2,500	15,000
5	150	1,250	10,000	25	450	3,000	20,000
7½	200	1,667	12,500	37½	600	3,750	25,000
10	250	2,000	16,667	50	750	5,000	30,000
15	333	2,500	20,000	75	1,000	6,000	37,500
25	500	3,333	25,000	100	1,200	7,500	50,000
37½	667	4,000	33,333	150	1,500	10,000	
50	...	5,000					

39. Standard Accessories for Transformers of 500 Kva. and Less

Rated circuit voltage	Oil drain plug (opening in tank to have ½-in. standard pipe thread)		Oil-sampling device		Oil drain valve (to be supplied as follows: transformer requiring 100 gal. and less, 1 in.; above 100 gal., 1½ in.)		Thermometer (opening in tank to have ½-in. standard pipe thread)		Oil gage (opening in tank to have ½-in. standard pipe thread)		Provisions for filter-press connections (See Note 3)		Hanger irons (as given below except none supplied on 3-phase transformers over 50 kva., 60 cycles and 25 kva., 25 cycles)	
	60 cycle	25 cycle	60 cycle	25 cycle	60 cycle	25 cycle	60 cycle	25 cycle	60 cycle	25 cycle	60 cycle	25 cycle	60 cycle	25 cycle
480	15–100	7½–50	15 and larger	7½ and larger	.....	.....	.....	.....	.....	.....	.....	.....	100 and smaller	50 and smaller
600	15–100	7½–50	15 and larger	7½ and larger	.....	.....	.....	.....	.....	.....	.....	.....	100 and smaller	50 and smaller
2,400	15–100	7½–50	15 and larger	7½ and larger	150–500	75–500	201–500	150–500	150–500	75–500	150–500	75–500	100 and smaller	50 and smaller
4,800	15–100	7½–50	15 and larger	7½ and larger	150–500	75–500	201–500	150–500	150–500	75–500	150–500	75–500	100 and smaller	50 and smaller
7,200	10–100	5 –50	10 and larger	5 and larger	150–500	75–500	201–500	150–500	150–500	75–500	150–500	75–500	50 and smaller	25 and smaller
7,620	10–100	5 –50	10 and larger	5 and larger	150–500	75–500	201–500	150–500	150–500	75–500	150–500	75–500	50 and smaller	25 and smaller
12,000	10–100	5 –50	10 and larger	5 and larger	150–500	75–500	201–500	150–500	150–500	75–500	150–500	75–500	50 and smaller	25 and smaller
13,800	10–100	5 –50	10 and larger	5 and larger	150–500	75–500	201–500	150–500	150–500	75–500	150–500	75–500	50 and smaller	25 and smaller
23,000	10– 37½	10 and 15 kva.	10 and larger	10 and larger	50–500	25–500	201–500	150–500	50–500	25–500	50–500	25–500		
34,500	15– 37½	15 kva.	15 and larger	15 and larger	50–500	25–500	201–500	150–500	50–500	25–500	50–500	25–500		
46,000	.....	.....	25 and larger	25 and larger	25–500	25–500	201–500	150–500	50–500	25–500	50–500	25–500	No hanger irons are regularly furnished with transformers in the 23,000-volt class or higher	
69,000	.....	.....	50 and larger	50 and larger	50–500	50–500	201–500	150–500	50–500	50–500	50–500	50–500		

NOTES: 1. Transformers in the 480- and 600-volt classes are standard for single-phase units only.

2. With a transformer of special rating, such accessories will be regularly furnished as would be supplied with a transformer of standard rating using the same mechanical parts.

3. Filter-press connections will consist of the following: the oil drain valve at the bottom for the bottom filter-press connection; a suitable opening with a standard 1-in. pipe thread above the oil level for the top filter-press connection.

4. Ventilators: The opening in the tank or cover for ventilators when supplied will have a 1-in. standard pipe thread.

40. Certain accessories are furnished as standard practice with transformers. The standard accessories for transformers of 200-kva. capacity or less are given in Sec. **39.**

Standard accessories for transformers above 200 kva. are as follows:

1. Oil gage, oil-drain valve, oil-sampling valve, and provision for filter-press connections.

2. Plain standard indicating thermometer for registering temperature of oil, except that for self-cooled transformers rated at 1,000 kva. or more and for all water-cooled transformers the thermometer is furnished with alarm contacts.

Large power transformers frequently are provided with means for indicating the temperature of the transformer windings.

41. Average data for distribution transformers are given in Secs. **42** to **56.** The tables will give approximate information for transformers with ratings on the low-voltage side of 120/240, 240/480, 600, or 2,400 volts.

42. Performance of 60-cycle, Single-phase, Oil-filled, Distribution Transformers

Standard Voltages of 600 or 2,400 Volts on High-voltage Side

Kva.	No load loss	Total loss at 75°C.	Efficiencies at 75°C.				Regulation at 75°C.		% impedance at 75°C.
			Full	¾	½	¼	100 % p.f.	80 % p.f.	
1½	20	66	95.8	96.1	95.9	94.2	3.1	3.6	3.6
3	27	98	96.9	97.1	97.1	96.0	2.4	2.6	2.5
5	41	134	97.4	97.6	97.5	96.4	1.9	2.6	2.5
7½	55	184	97.6	97.8	97.7	96.8	1.8	2.3	2.3
10	59	241	97.7	97.9	97.9	97.3	1.9	2.3	2.3
15	80	333	97.8	98.0	98.1	97.5	1.7	2.2	2.2
25	120	496	98.1	98.3	98.3	97.7	1.6	2.7	2.9
37½	154	649	98.3	98.5	98.5	98.1	1.4	2.6	2.8
50	190	795	98.4	98.6	98.6	98.2	1.3	2.3	2.5
75	288	1194	98.4	98.6	98.6	98.1	1.3	3.1	3.6
100	357	1553	98.5	98.6	98.7	98.2	1.3	3.2	3.8
150	550	2292	98.5	98.7	98.7	98.3	1.3	3.8	4.8
200	800	2905	98.6	98.7	98.7	98.2	1.2	3.7	4.8
250	1115	3815	98.5	98.6	98.6	98.0	1.2	3.7	4.8
333	1310	4665	98.6	98.7	98.7	98.2	1.2	3.7	4.8
500	1675	6325	98.8	98.9	98.9	98.5	1.1	3.6	4.8

43. Performance of 60-cycle, Single-phase, Oil-filled, Distribution Transformers

Standard Voltages of 7,200 Volts on High-voltage Side

Kva.	No load loss	Total loss at 75°C.	Efficiencies at 75°C.				Regulation at 75°C.		% impedance at 75°C.
			Full	¾	½	¼	100 % p.f.	80 % p.f.	
1½	22	65	95.9	96.1	95.8	93.8	2.9	2.9	3.0
3	32	106	96.6	96.9	96.7	95.4	2.6	3.1	3.0
5	51	164	96.8	97.1	96.9	95.6	2.3	2.5	2.6
7½	59	229	97.0	97.3	97.3	96.4	2.3	3.0	3.0
10	71	288	97.2	97.5	97.6	96.8	2.3	3.0	3.0
15	97	364	97.6	97.9	97.9	97.1	1.9	3.1	3.3
25	144	544	97.9	98.1	98.1	97.4	1.7	3.1	3.4
37½	208	725	98.1	98.3	98.2	97.5	1.5	2.9	3.2
50	270	940	98.2	98.3	98.3	97.6	1.4	3.1	3.6
75	370	1310	98.3	98.4	98.4	97.8	1.4	4.0	5.1
100	470	1700	98.3	98.5	98.4	97.8	1.4	3.8	4.8
150	725	2425	98.4	98.5	98.5	97.8	1.3	3.9	5.0
200	915	3180	98.4	98.6	98.5	97.9	1.3	3.9	5.0
250	1115	3815	98.5	98.6	98.6	98.0	1.3	3.9	5.0
333	1310	4665	98.6	98.7	98.7	98.2	1.2	3.8	5.0
500	1675	6325	98.8	98.9	98.9	98.5	1.1	3.8	5.0

44. Performance of 60-cycle, Single-phase, Oil-filled, Distribution Transformers

Standard Voltage of 13,200 Volts on High-voltage Side

Kva.	No load loss	Total loss at 75°C.	Efficiencies at 75°C.				Regulation at 75°C.		% impedance at 75°C.
			Full	¾	½	¼	100 % p.f.	80 % p.f.	
2½	44	113	95.7	95.8	95.3	92.8	2.7	3.1	3.1
5	58	180	96.5	96.8	96.6	95.0	2.5	2.9	2.9
10	92	288	97.2	97.4	97.2	96.0	2.0	2.8	2.8
15	122	396	97.4	97.6	97.5	96.4	1.9	2.9	3.0
25	170	550	97.9	98.0	97.9	97.0	1.6	3.0	3.3
37½	230	748	98.1	98.2	98.1	97.3	1.5	3.0	3.3
50	300	958	98.1	98.3	98.2	97.4	1.4	2.9	3.2
75	415	1375	98.2	98.3	98.3	97.5	1.4	4.0	5.0
100	530	1755	98.3	98.4	98.3	97.6	1.4	4.0	5.1
150	750	2520	98.3	98.5	98.4	97.8	1.3	3.9	5.0
200	950	3240	98.4	98.5	98.5	97.9	1.3	3.9	5.0
250	1115	3815	98.5	98.6	98.6	98.0	1.3	3.9	5.0
333	1310	4665	98.6	98.7	98.7	98.2	1.2	3.8	5.0
500	1675	6325	98.8	98.9	98.9	98.5	1.1	3.8	5.0

45. Performance of 60-cycle, Single-phase, Oil-filled, Distribution Transformers

Standard Voltage of 22,000 Volts on High-voltage Side

Kva.	No load loss	Total loss at 75°C.	Efficiencies at 75°C.				Regulation at 75°C.		% impedance at 75°C.
			Full	¾	½	¼	100 % p.f.	80 % p.f.	
10	135	420	96.0	96.2	96.0	94.2	3.0	4.9	5.2
15	175	530	96.6	96.8	96.6	95.0	2.5	4.7	5.2
25	230	740	97.1	97.3	97.2	96.0	2.2	4.6	5.2
37½	300	985	97.4	97.6	97.5	96.4	2.0	4.5	5.2
50	375	1225	97.6	97.8	97.7	96.7	1.9	4.4	5.2
75	500	1630	97.9	98.0	98.0	97.0	1.7	4.2	5.2
100	610	1995	98.1	98.2	98.1	97.3	1.7	4.2	5.2
150	825	2715	98.2	98.3	98.3	97.5	1.4	4.1	5.2
200	1015	3430	98.3	98.4	98.4	97.7	1.4	4.1	5.2
250	1200	3930	98.5	98.6	98.5	97.8	1.3	4.0	5.2
333	1450	4810	98.6	98.7	98.6	98.0	1.2	4.0	5.2
500	1950	6570	98.8	98.8	98.8	98.2	1.1	3.9	5.2

46. Performance of 60-cycle, Single-phase, Oil-filled, Distribution Transformers

Standard Voltage of 44,000 Volts on High-voltage Side

Kva.	No load loss	Total loss at 75°C.	Efficiencies at 75°C.				Regulation at 75°C.		% impedance at 75°C.
			Full	¾	½	¼	100 % p.f.	80 % p.f.	
25	310	858	96.7	96.8	96.5	94.8	2.4	5.0	5.7
37½	400	1122	97.1	97.2	97.0	95.5	2.1	4.8	5.7
50	490	1370	97.3	97.4	97.2	95.8	2.0	4.8	5.7
75	630	1810	97.6	97.7	97.6	96.4	1.8	4.6	5.7
100	770	2225	97.8	97.9	97.8	96.7	1.7	4.6	5.7
150	1010	3003	98.0	98.1	98.0	97.1	1.5	4.5	5.7
200	1230	3743	98.2	98.3	98.2	97.3	1.5	4.4	5.7
250	1420	4405	98.3	98.4	98.3	97.5	1.4	4.4	5.7
333	1695	5395	98.4	98.5	98.5	97.7	1.3	4.4	5.7
500	2200	7030	98.6	98.7	98.7	98.0	1.2	4.3	5.7

47. Performance of 60-cycle, Single-phase, Oil-filled, Distribution Transformers

Standard Voltage of 66,000 Volts on High-voltage Side

Kva.	No load loss	Total loss at 75°C.	Efficiencies at 75°C.				Regulation at 75°C.		% impedance at 75°C.
			Full	¾	½	¼	100 % p.f.	80 % p.f.	
50	640	1515	97.1	97.1	96.7	94.7	2.0	5.3	6.5
75	820	1950	97.5	97.5	97.1	95.5	1.8	5.1	6.5
100	970	2385	97.7	97.7	97.4	95.9	1.7	5.1	6.5
150	1220	3160	97.9	98.0	97.8	96.5	1.5	5.0	6.5
200	1440	3900	98.1	98.1	98.0	96.9	1.5	4.9	6.5
250	1630	4615	98.2	98.3	98.1	97.2	1.4	4.9	6.5
333	1875	5635	98.3	98.4	98.3	97.5	1.4	4.9	6.5
500	2400	7380	98.5	98.6	98.6	97.9	1.3	4.8	6.5

48. Performance of 60-cycle, Three-phase, Oil-filled, Distribution Transformers

Standard Voltage of 2,400 Volts on High-voltage Side

Kva.	No load loss	Total loss at 75°C.	Efficiencies at 75°C.				Regulation at 75°C.		% impedance, at 75°C.
			Full	¾	½	¼	100 % p.f.	80 % p.f.	
10	90	345	96.7	97.0	97.0	96.0	2.6	3.4	3.4
15	113	443	97.1	97.4	97.5	96.5	2.3	3.3	3.4
25	162	650	97.5	97.7	97.8	97.0	2.0	3.3	3.4
37½	214	890	97.7	97.9	98.0	97.3	1.9	3.9	4.3
50	275	1117	97.8	98.0	98.1	97.4	1.9	4.2	4.9
75	370	1525	98.0	98.2	98.2	97.7	1.7	3.8	4.4
100	455	1860	98.2	98.4	98.4	97.9	1.5	3.8	4.6
150	59¢	2445	98.4	98.6	98.6	98.1	1.4	3.4	4.1
200	785	3093	98.5	98.6	98.6	98.2	1.3	3.4	4.2
300	1100	4350	98.6	98.7	98.7	98.3	1.2	3.7	4.8
450	1550	6125	98.4	98.8	98.8	98.6	1.2	3.7	4.8

49. Performance of 60-cycle, Three-phase, Oil-filled, Distribution Transformers

Standard Voltage of 4,800 Volts on High-voltage Side

Kva.	No load loss	Total loss at 75°C.	Efficiencies at 75°C.				Regulation at 75°C.		% impedance at 75°C.
			Full	¾	½	¼	100 % p.f.	80 % p.f.	
10	94	354	96.6	96.9	96.9	95.8	2.7	3.7	3.7
15	120	465	97.0	97.3	97.3	96.3	2.4	3.7	3.8
25	170	685	97.3	97.6	97.7	96.9	2.2	3.4	3.5
37½	225	935	97.6	97.8	97.9	97.2	2.0	3.7	4.0
50	275	1165	97.7	98.0	98.0	97.4	1.9	3.6	4.0
75	370	1585	97.9	98.2	98.2	97.7	1.8	3.5	4.0
100	455	1955	98.1	98.3	98.3	97.8	1.6	3.5	4.0
150	615	2615	98.3	98.5	98.5	98.0	1.4	3.4	4.0
200	785	3275	98.4	98.6	98.6	98.1	1.4	3.4	4.0
300	1100	4350	98.6	98.7	98.7	98.3	1.2	3.7	4.8
450	1550	6125	98.7	98.8	98.8	98.4	1.2	3.7	4.8

50. Performance of 60-cycle, Three-phase, Oil-filled, Distribution Transformers

Standard Voltage of 7,200 Volts on High-voltage Side

Kva.	No load loss	Total loss at 75°C.	Efficiencies at 75°C.				Regulation at 75°C.		% impedance at 75°C.
			Full	¾	½	¼	100 % p.f.	80 % p.f.	
10	100	385	96.3	96.7	96.7	95.5	2.9	2.9	3.0
15	132	512	96.7	97.0	97.0	96.0	2.6	3.3	3.3
26	190	735	97.2	97.4	97.5	96.5	2.3	3.4	3.5
37½	260	1000	97.4	97.7	97.7	96.9	2.1	3.4	3.5
50	315	1205	97.7	97.9	97.9	97.1	1.9	3.1	3.2
75	440	1650	97.8	98.0	98.0	97.3	1.7	3.1	3.4
100	560	2050	98.0	98.2	98.1	97.4	1.6	3.4	3.9
150	730	2760	98.2	98.4	98.4	97.8	1.5	3.5	4.2
200	850	3370	98.4	98.5	98.5	98.0	1.4	3.5	4.2
300	1150	4470	98.5	98.7	98.7	98.2	1.3	3.9	5.0
450	1600	6300	98.6	98 8	98.8	98.3	1.2	3.9	5.0

51. Performance of 60-cycle, Three-phase, Oil-filled, Distribution Transformers

Standard Voltage of 12,000 Volts on High-voltage Side

Kva.	No load loss	Total loss at 75°C.	Efficiencies at 75°C.				Regulation at 75°C.		% impedance at 75°C.
			Full	¾	½	¼	100 % p.f.	80 % p.f.	
10	110	410	95.1	96.4	96.4	95.1	3.1	4.7	4.8
15	145	545	96.5	96.8	96.8	95.7	2.8	4.7	5.0
25	207	775	97.0	97.3	97.3	96.2	2.4	3.7	4.0
37½	275	1035	97.3	97.6	97.6	96.7	2.2	3.7	4.0
50	345	1275	97.5	97.7	97.7	96.9	2.0	3.9	4.3
75	475	1745	97.7	97.9	97.9	97.1	1.9	3.9	4.6
100	600	2160	97.9	98.1	98.1	97.3	1.8	4.6	5.7
150	765	2895	98.1	98.3	98.3	97.6	1.5	3.7	4.4
200	890	3540	98.3	98.4	98.4	97.9	1.4	3.6	4.4
300	1225	4795	98.4	98.6	98.6	98.1	1.4	3.9	5.0
450	1650	6690	98.5	98.7	98.7	98.3	1.3	3.9	5.0

52. Performance of 60-cycle, Three-phase, Oil-filled, Distribution Transformers

Standard Voltage of 13,200 Volts on High-voltage Side

Kva.	No load loss	Total loss at 75°C.	Efficiencies at 75°C.				Regulation at 75°C.		% impedance at 75°C.
			Full	¾	½	¼	100 % p.f.	80 % p.f.	
15	165	565	96.4	96.7	96.6	95.2	2.8	4.6	4.8
25	230	800	96.9	97.2	97.1	96.0	2.4	3.6	3.6
37½	305	1065	97.3	97.5	97.4	96.4	2.2	4.1	4.5
50	375	1305	97.5	97.7	97.6	96.6	2.0	4.0	4.5
75	515	1785	97.7	97.9	97.8	96.9	1.8	3.2	3.5
100	630	2190	97.9	98.0	98.0	97.2	1.7	4.5	5.5
150	790	2920	98.1	98.3	98.2	97.6	1.6	3.8	4.5
200	930	3580	98.3	98.4	98.4	97.8	1.5	3.7	4.5
300	1225	4795	98.4	98.6	98.6	98.1	1.4	3.9	5.0
450	1650	6690	98.5	98.7	98.7	98.3	1.3	3.9	5.0

53. Performance of 60-cycle, Three-phase, Oil-filled, Distribution Transformers

Standard Voltage of 22,000 Volts on High-voltage Side

Kva.	No load loss	Total loss at 75°C.	Efficiencies at 75°C.				Regulation at 75°C.		% impedance at 75°C.
			Full	¾	½	¼	100 % p.f.	80 % p.f.	
37½	330	1250	96.8	97.1	97.1	96.1	2.6	4 8	5.2
50	385	1510	97.1	97.4	97.4	96.5	2.4	4 7	5.2
75	525	1945	97.4	97.7	97.7	96.8	2.1	4 5	5.2
100	640	2365	97.7	97.9	97.9	97.1	1.9	4 4	5.2
150	800	3085	98.0	98.2	98.2	97.6	1.7	4 3	5.2
200	985	3815	98.1	98.3	98.3	97.7	1.6	4.2	5.2
300	1355	5320	98.3	98.4	98.5	97.9	1.5	4.2	5.2
450	1850	7100	98.4	98.6	98.6	98.1	1.3	4.1	5.2

54. Performance of 60-cycle, Three-phase, Oil-filled, Distribution Transformers

Standard Voltage of 44,000 Volts on High-voltage Side

Kva.	No load loss	Total loss at 75°C.	Efficiencies at 75°C.				Regulation at 75°C.		% impedance at 75°C.
			Full	¾	½	¼	100 % p.f.	80 % p.f.	
75	675	2230	97.1	97.3	97.2	96.0	2.3	4.9	5.7
100	840	2635	97.4	97.6	97.5	96.3	2.0	4.7	5.7
150	1100	3485	97.7	97.9	97.8	96.8	1.8	4.6	5.7
200	1350	4290	97.9	98.0	98.0	97.0	1.7	4.6	5.7
300	1765	5830	98.1	98.2	98.2	97.4	1.6	4.5	5.7
450	2340	7865	98.3	98.4	98.4	97.7	1.4	4.4	5.7

55. Performance of 60-cycle, Three-phase, Oil-filled, Distribution Transformers

Standard Voltage of 66,000 Volts on High-voltage Side

Kva.	No load loss	Total loss at 75°C.	Efficiencies at 75°C.				Regulation at 75°C.		% impedance at 75°C.
			Full	¾	½	¼	100 % p.f.	80 % p.f.	
150	1450	3970	97.4	97.5	97.3	95.9	1.9	5.2	6.5
200	1700	4800	97.7	97.8	97.6	96.4	1.8	5.2	6.5
300	2200	6340	97.9	98.0	97.9	96.8	1.6	5.0	6.5
450	2850	8420	98.2	98.3	98.1	97.2	1.5	4.9	6.5

56. Performance of 60-cycle, Single-phase, Air-cooled Transformers

Standard Voltage of 2,400 Volts on High-voltage Side

Kva.	No load loss	Total loss at 75°C.	Efficiencies at 75°C.				Regulation at 75°C.		% impedance at 75°C.
			Full	¾	½	¼	100 % p.f.	80 % p.f.	
150	755	2265	98.51	98.60	98.51	97.78	1.2	3.8	5.0
200	925	2890	98.58	98.66	98.60	97.95	1.1	3.8	5.0
250	1080	3495	98.62	98.72	98.67	98.07	1.1	3.8	5.0
333	1325	4460	98.68	98.78	98.75	98.20	1.1	3.6	5.0
500	1760	6315	98.75	98.86	98.85	98.39	1.1	3.7	5.0

57. Small power transformers (Figs. 5 and 26) are constant-potential, self-air-cooled transformers for industrial purposes. The windings are completely enclosed in metal casings. They are available in single and three-phase construction of conventional or autotransformer types with cases designed for open or conduit wiring. Single-phase units are available in sizes up to 50 kva., while three-phase units are made as large as 150 kva. Primary voltage ratings range from 125 to 2,400. Standard secondary voltages are 115/230 or 230/460.

58. Small power transformers (Fig. 27) are available for taking power from motor disconnecting switches for localized lighting at the machine.

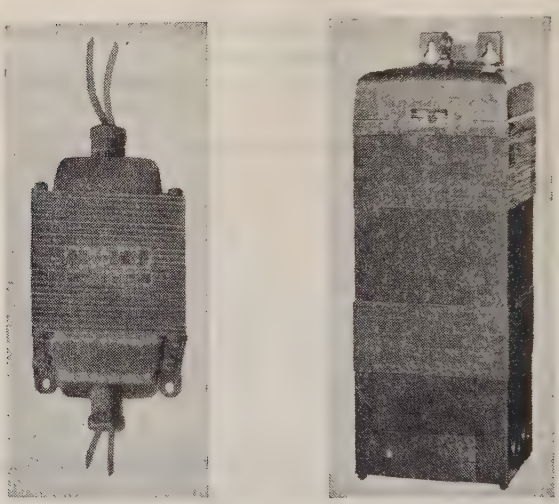


FIG. 26.—Small power transformers, self air-cooled. (*General Electric Co.*)

Types are available for operating 115-, 64-, 32-, or 6-volt lamps from 115-, 230-, 460-, or 575-volt power circuits. Standard sizes are 75, 150, 225, and 300 watts.

59. Sign-lighting transformers are single-phase, constant-potential, self-air-cooled transformers for stepping down from 115 or 230 volts to the proper voltage for low-voltage incandescent lamps in signs. They are made in sizes up to 5 kva. with the windings completely enclosed in metal casings.

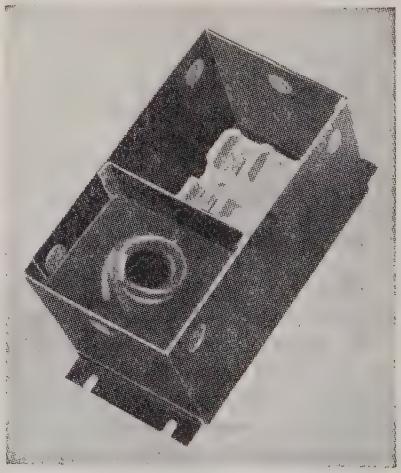
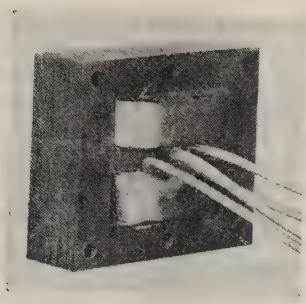
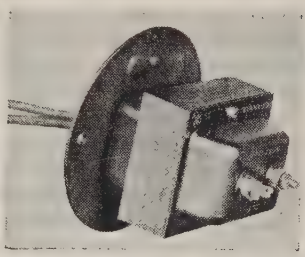


FIG. 27.—Small power transformer for unit machine lighting. (*American Transformer Co.*)

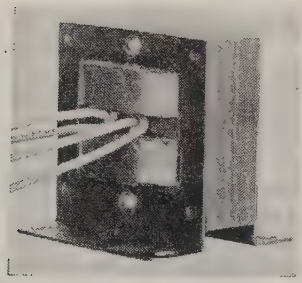
60. Control and signal transformers are constant-potential, self-air-cooled transformers for the purpose of supplying the proper voltage for control circuits of electrically operated switches or other equipment and for signal circuits. They may be of the open type with no protective casing over the windings or of the enclosed type with a metal casing over the windings. Some of the available mounting types are shown in Fig. 28.



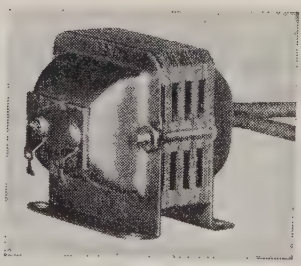
I



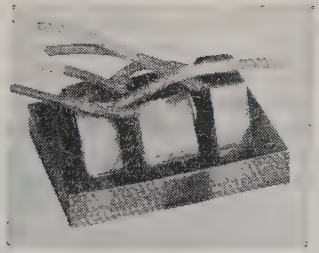
IV



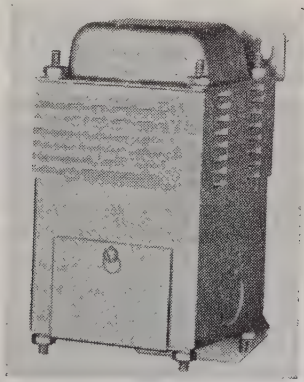
II



V



III



VI

FIG. 28.—Control and signal transformers. (I) Core-and-coils, only. (II) Core-and-coils, with mounting feet. (III) Transformer with two secondary windings. (IV) Core-and-coils with end cases and plate for junction-box mounting. (V) Core-and-coils, with end cases, high-voltage leads, low-voltage solder lugs. (VI) Transformer with junction box. (*General Electric Co.*)

61. Transformers for many gaseous-discharge lamps must be of the varying-voltage type. These transformers are designed so that the secondary voltage drops rapidly with load. This voltage characteristic is accomplished by means of a three-winding transformer with magnetic leakage paths between the primary and each secondary, as shown in Fig. 29. As the load increases, the leakage flux of the primary produces a greater voltage drop in the primary winding, thereby reducing the secondary voltage. Some of these transformers are equipped with a capacitor mounted inside the same enclosing case, for power-factor improvement. The transformers are of the self-air-cooled type. Various mounting types for luminous-tube work are shown in Fig. 30.

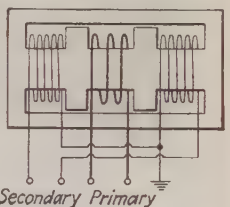
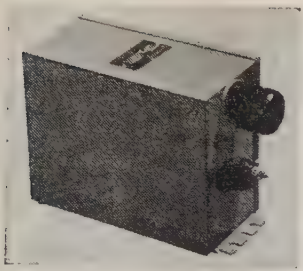


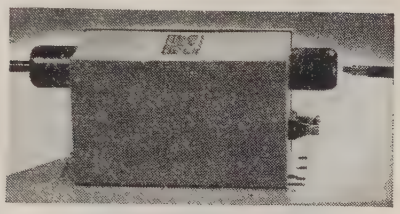
FIG. 29.—Cross section of a typical neon-sign transformer, showing windings and leakage paths in magnetic circuit.

62. Bell-ringing transformers (Fig. 31) are especially designed small-capacity, constant-potential transformers for applications such as the operation of doorbells, buzzers, door openers, and annunciators. They are self-air-cooled units enclosed in metal cases. They may be obtained for primary voltages of 120 or 240 with a single secondary voltage of 10 or with three secondary voltages of 6, 12, and 18.

63. Instrument transformers are employed for the purpose of stepping down the voltage or current of a circuit for the operation of instruments, such as ammeters, voltmeters, wattmeters, etc., and relays for various protective purposes. It would be practically impossible to build delicate devices such as instruments and relays so that they would have satisfactory insulation for high voltages. Frequently such devices while energized must be accessible to operators, so that it is necessary to have the devices insulated from the high-voltage circuit. Instrument transformers are of two types: potential and current. They are made in various types depending upon the voltage of the circuits, requirements of installations, and accuracy required. Instrument transformers will always introduce a certain amount of error into the readings obtained on instruments supplied by them. The transformers are not rated on a thermal basis of the load which they can safely carry, but upon an accuracy basis. The volt-ampere rating is the load which the transformer will carry without exceeding the specified accuracy limit. If accuracy can be sacrificed, the transformers can be used for loads considerably above their rated values. Instrument transformers are made in indoor, outdoor, and portable types for test purposes. Potential transformers have a normal secondary voltage of 120 volts. Current transformers have a normal secondary current of 5 amp. Typical instrument transformers are shown in Figs. 32 and 33.

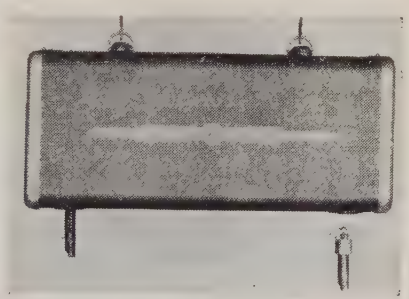


I. High-power factor transformer.

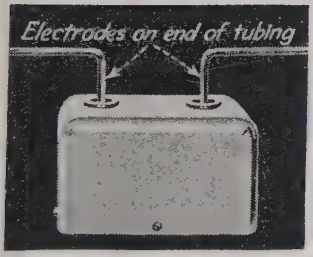


II. Low-power factor transformer, showing how high-voltage cables are attached.

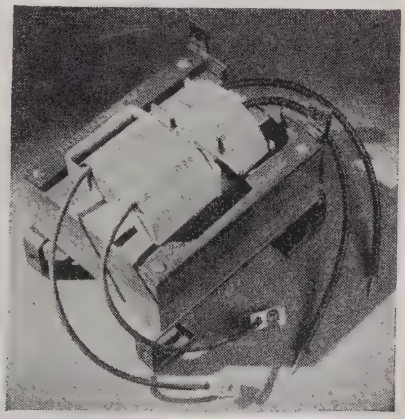
III. Thin type transformer for 7,500 volts or below.



IV. Combination suspension or standing type indoor transformer. Arranged for suspension from ceiling by hanger brackets.

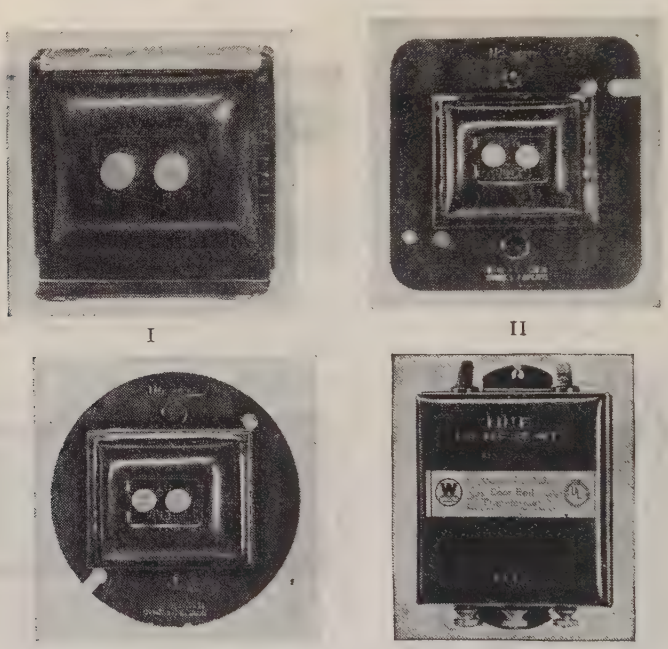


V. Electrode type transformer.



VI. Transformer without casing.

FIG. 30.—Various types of luminous-tube transformers. (*General Electric Co.*)



I II III IV

FIG. 31.—Bell-ringing transformers. (I) Conventional transformer. (II) Transformer for square outlet box mounting. (III) Transformer for round or octagonal outlet box mounting. (IV) Transformer with three available secondary voltages. (*Westinghouse Electric & Manufacturing Co.*)

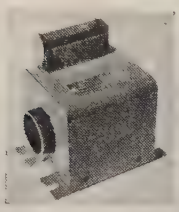
64. Standard Accuracies for Current Transformers for Metering Service

(Standards for relay service have not been established)

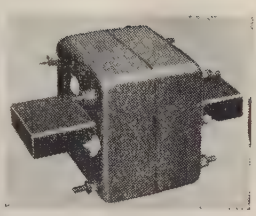
Class	Limits of ratio error, per cent		Limits of phase angle, min.	
	100 per cent rated current	10 per cent rated current	100 per cent rated current	10 per cent rated current
1	±1	±2	±40	±80
½	±0.5	±1	±20	±40
¼	±0.25	±0.5	±10	±20
M	[a]	[a]	[a]	[a]

[a] Class *M* accuracy is applicable to 1,000-volt service or less and *X* burden only. The ratio and phase-angle limits shall be such that their combined effect on the accuracy of the current transformer, from 10 to 150 per cent of rated current and at any load power factor from 50 per cent lagging to unity, shall not produce an error exceeding 0.5 per cent at the watthour meter.

Type W-1, three-wire

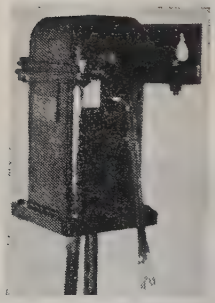


Type Fw

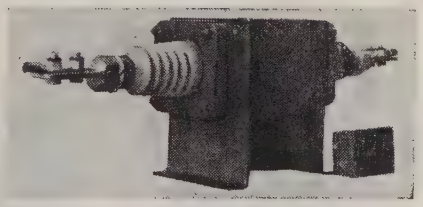


Type FB

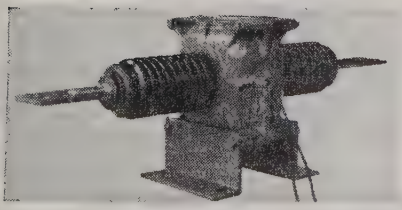
I



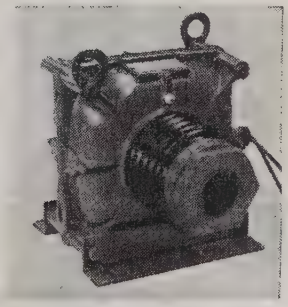
Type WO



Type RO



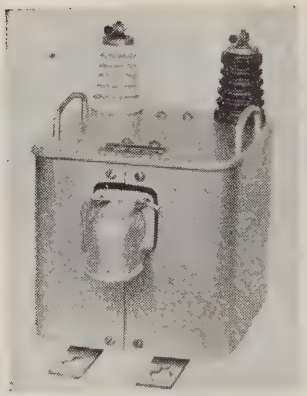
Type UO



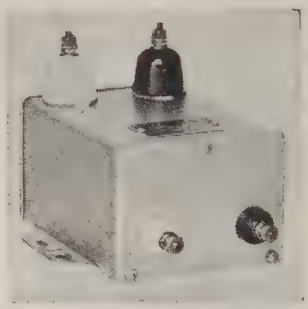
Type HO

II

FIG. 32.—Typical current instrument transformers. (I) Indoor types. (II) Outdoor types. (*Westinghouse Electric & Manufacturing Co.*)

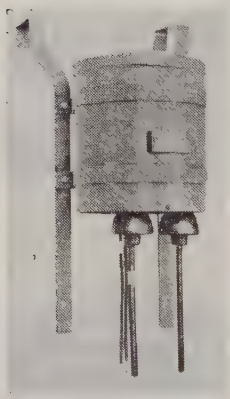


I

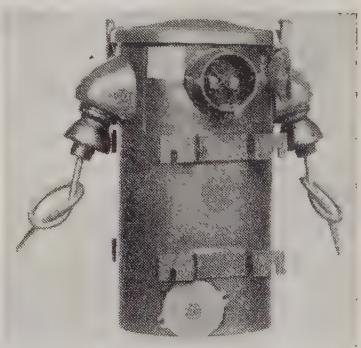


II

A.



III



IV

B.

FIG. 33.—Typical potential instrument transformers. (I) Dry-type transformer 6210–7590, 11,500 and 13,800 volts. (II) Fifty-volt-amp., 60-cycle, 2,200-volt, dry-type transformer. (III) Dry type, 6,600 volts. (IV) Oil type, 13,200 volts. *A* are indoor types; *B* outdoor types. (*General Electric Co.*)

65. Standard Accuracies for Potential Transformers

Class	Limits of ratio error, per cent	Limits of phase angle, min.
1	±1	±40
½	±0.5	±20
¼	±0.25	±10

These limits shall apply from 10 per cent above rated voltage to 10 per cent below rated voltage, at rated frequency.

66. The current transformer ("Standard Handbook") considered electrically, and omitting any reference to the change in its design to accomplish its specific duty, differs from the shunt or potential transformer merely in the method of use. The latter transformer is ordinarily supplied with a constant impressed voltage, the load being changed by varying the impedance (load) of the total secondary circuit, while the total impedance of the secondary circuit of the former transformer is normally held constant, and the change in load is due to a simultaneous change in the primary current and e.m.f. In the potential transformer the actual ratio of the primary to the secondary current is of minor importance, while every effort is made to design the apparatus so that the ratio of the secondary power to the primary power is as nearly unity as possible. In the design of a series transformer no thought whatsoever is given to the ratio of the primary and secondary watts, but attention is concentrated on the endeavor to obtain a definite ratio of secondary to primary amperes.

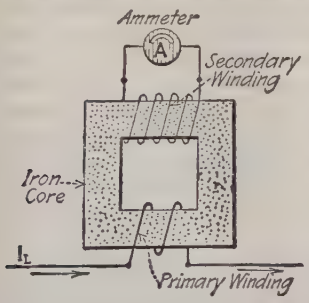


FIG. 34.—Elementary series transformer.

The electric and magnetic circuits of a current transformer can conveniently be represented by the diagram shown in Fig. 34, where it is used for reducing the line current to a value suitable for measurement by a low-reading ammeter, which may be thoroughly insulated from the main circuit. Neglecting the small transformer loss, the current through the ammeter A is, since the ratio of turns $M = 2:5$, equal to two-fifths the line current I_L.

67. Application of the Current Instrument Transformer.—When an alternating current is so large that to connect measuring or operating instruments directly in the circuit would be impracticable, or when the voltage is so high that to do so would be unsafe, the current transformer provides a means of reproducing the effect of the primary current on a scale suited to the instrument and of insulating the instrument from the main circuit. It is a special development of the transformer principle in which a constant ratio of primary to secondary current is the important consideration instead of the usual constant ratio of primary to secondary voltage.

Current transformers are used with a-c ammeters, wattmeters, power-factor meters, watthour meters, compensators, protective and regulating relays, and the trip coils of circuit breakers. It is a standard practice in this country to design current transformers (regardless of their capacity or ratios of transformation) to supply a rated secondary current of 5 amp.

Example.—A 600-amp. current transformer has a ratio of 120:1, *i.e.*, when a current of 600 amp. flows in the primary circuit, 600 ÷ 120 = 5 amp. will flow in the secondary circuit.

Measuring instruments for use with these transformers are so designed and are provided with scales such that they give a normal scale deflection when 5 amp. flows through them.

68. It is unsafe to open the secondary circuit of a current transformer when there is any current in the primary. When the secondary circuit is closed, the current in this circuit creates a m.m.f. which is in opposition to the m.m.f. of the primary current, and the core flux is thereby limited to the value necessary to generate in the secondary coil an e.m.f. sufficient to produce therein a current only slightly less than the primary current in magnetizing effect. When the secondary is open there is no opposing m.m.f. for limiting the core flux, which may reach a high value. Thus even a small value of primary current produces an excessive value of core flux and a correspondingly large secondary e.m.f. The secondary voltage under these conditions reaches a value which may both damage the insulation and prove dangerous to life. Absolutely no harm can come from short-circuiting the secondary terminals of the current transformer, and this method is used when it is necessary to insert or disconnect instruments in the secondary circuit.

69. The Constant-current Transformer ("Standard Handbook").—The operation of low-voltage lamps in parallel on a constant-potential system necessitates a prohibitive expenditure for conducting material when the area to be lighted is extensive and the lamps are widely separated. For such service it is the common practice to operate the lamps, which are connected in series, with a constant current. The constant-current transformer is a special form of transformer which converts alternating current at a constant potential to a constant (alternating) current with a voltage varying with the load. It consists of a primary coil upon which the constant voltage is impressed, a secondary coil (or coils) movable with respect to the primary, and a core of low magnetic reluctance. It depends for its regulation upon the magnetic leakage between the primary and secondary coils.

Consider first the primary coil; with the constant e.m.f. impressed upon this coil the total magnetism within the coil will be practically constant under all conditions. The e.m.f. generated in the secondary will depend upon the strength of the field which it surrounds. In all types of stationary transformers the secondary current is opposite in general time direction to the primary, so that not only is there a repulsive thrust between the two coils but also a considerable tendency for the magnetic lines from the primary to be forced out into space without penetrating the secondary. In the ordinary constant-potential transformer the repelling action between the two currents is prevented from producing

motion of the coils by the rigid mechanical construction, while the proximity of the primary and secondary coils limits the magnetic leakage.

In the constant-current transformer, however, the repelling action is utilized to adjust the relative positions of the primary and secondary coils; when the coils are widely separated the paths for the leakage lines are increased and the lines which the secondary surrounds are fewer than when the coils are quite close together. The counterweights mechanically attached to the movable coil (or coils) are so arranged that when the desired current exists in the secondary coil (independent of its position along the core) the weights are just balanced. An increase in the current increases the repulsion and causes the coils to separate. With any current less than normal, the repelling force diminishes and the primary and secondary coils approach each other, thereby restoring the current to normal. The primary can be wound for any reasonable potential (say as high as 10,000 volts) while the secondary can be wound for the voltage required for operating the number of lamps in the circuit—from 15 to 200 or more lamps.

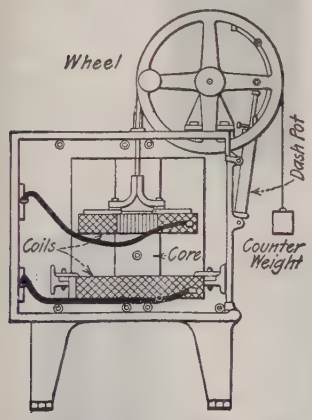


FIG. 35.—Constant-current transformer.

70. Mechanical Construction of the Constant-current Transformer.—The magnetic circuit of a constant-current transformer is usually of the "shell" type, the three limbs being placed vertically. In small sizes (Fig. 35) one of the coils is arranged in a fixed position while the other is movable. In some of the larger sizes there are two fixed primary coils and two movable secondary coils, while in others both the primary and secondary coils are movable. In any event the gravitational action on the movable coil, or the gravitational action of one movable coil against another to which it is mechanically interconnected, is counterbalanced accurately with an excess or deficiency just equal to the repulsive thrust of the primary and secondary coils at the desired load current. By the use of cam mechanisms for the counterweights, or of eccentrically placed extra weights, the excess force of the counterweights may be arranged to be equal to the variable repulsive thrust corresponding to a constant value of current in the coils at all positions of the movable coils. In fact, the transformer may be adjusted to regulate for a current of constant value at all loads or for one which either increases or decreases with increase of loads, while both the real value of the load current and its rate of change with the variation in load may be adjusted at will. In

order to prevent any "hunting" action of the movable coils each transformer is sometimes equipped with a dashpot (see Fig. 35).

71. Commercial constant-current transformers are built for natural air cooling or for immersion in oil. Oil has proved an excellent medium

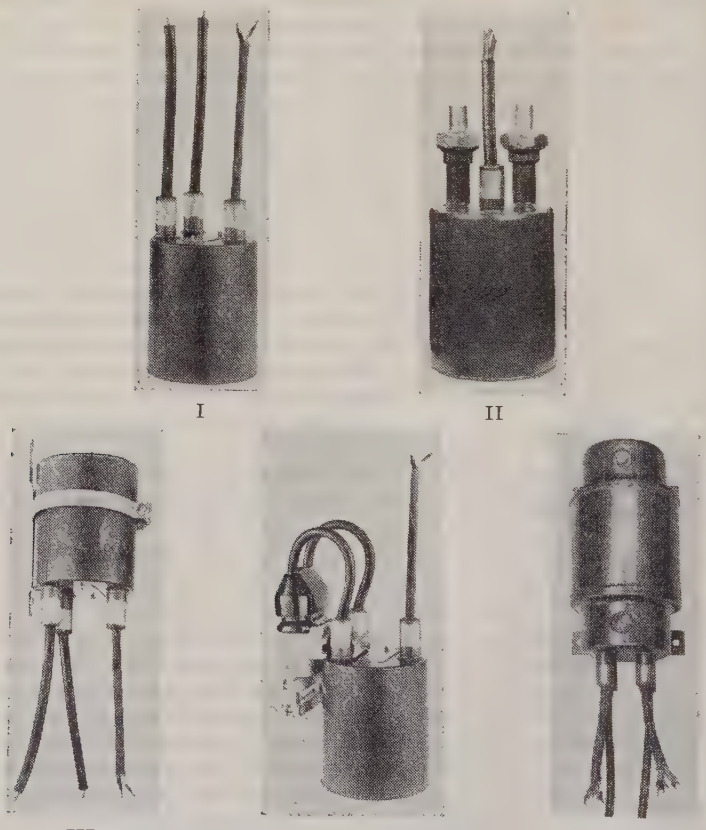


FIG. 36.—Series transformers for operation from series street-lighting circuits. (I) Type with wiping nipples. (II) Manhole type with primary disconnecting terminals. (III) Aerial type. (IV) Combined transformer with disconnecting pothead. (V) Group series transformer, aerial or subway type, 1 to 4 kva. (*Westinghouse Electric & Manufacturing Co.*)

for insulation, cooling, and lubrication. This type of transformer is extensively used for series street-lighting service with either gaseous-discharge or incandescent lamps. The efficiency of a constant-current transformer is high, being about 96 per cent at full load for a 100-lamp

transformer. The power factor, which depends upon the magnetic leakage, is low at all loads; it reaches from 75 to 80 per cent at full-load and decreases therefrom in almost direct proportion to the decrease in load.

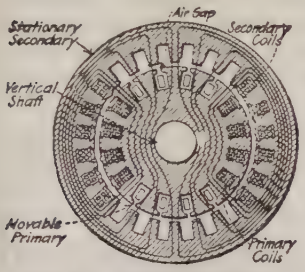


FIG. 37.—Section through a single-phase, induction-type, potential regulator.

Constant-current transformers are made in outdoor-pole-mounting, subway-mounting, and indoor-station types. A primary voltage of 2,400 is standard. The secondary current may be 6.6 or 20 amp. The standard ratings are 5, 10, 15, 20, 25, 30, 35, 40, 50, 60, and 70 kw.

72. Series transformers are for use with series incandescent street lamps for operation of lamps at a different value of current from that of the main series circuit or for isolation of a lamp of the same current value as the main circuit from the main circuit, which operates at a high voltage. The principle of operation is the same as for instrument current transformers. The primary is connected in series with the main series circuit. The lamp or lamps are connected to the secondary. These transformers are made in single-lamp types for operating one 6.6-, 15-, or 20-amp. series lamp from a 6.6-amp. main circuit; in two-lamp series type for operating two 6.6-, 15-, or 20-amp. series lamps connected in series to the secondary; in two-lamp multiple type for operating two 6.6-, 15-, or 20-amp. series lamps connected to two separate secondaries; in group series type for operating a group of 6.6-amp. series lamps connected in series to the secondary; and in single-lamp type for operating a single 115-volt lamp

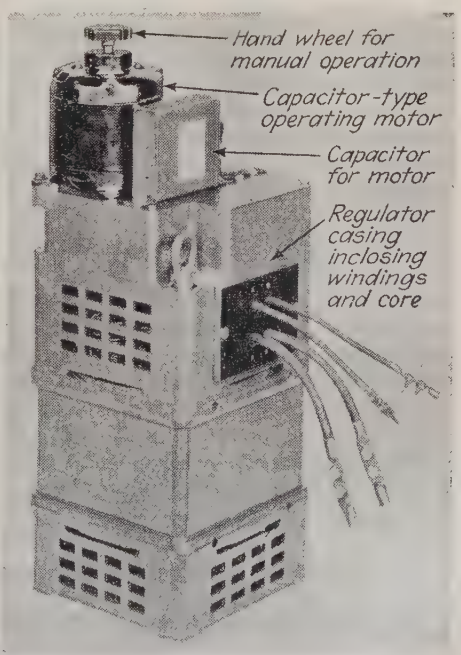


FIG. 38.—Motor-operated 3.6-kva. regulator complete, showing lead construction.

from a series 6.6-amp. main circuit. The group series type is made in ratings of 0.25, 0.5, 1.0, 2, 3, 4, 5, 7.5, and 9.0 kva. The single-lamp type for 115-volt lamp is made in sizes to accommodate one lamp of any watt size from 40 to 1,000 watts. They are made in types for vault or subway mounting, for mounting in base of ornamental lighting pole, and for pole mounting (Fig. 36).

73. The induction regulator (Figs. 37 and 38) is a special type of transformer, built like an induction motor with a coil-wound secondary, which is used for varying the voltage delivered to a synchronous converter or a-c feeder system. In comparison with a variable-ratio transformer it possesses the advantage of being operated without opening the circuit and without short-circuiting any transformer coil. The primary of the induction regulator is subjected to the constant voltage of the supply system, the delivered voltage obtained from the secondary winding being varied by rotating the primary structure through a certain number of degrees with reference to the secondary structure. The primary structure is normally stationary, although it is movable either automatically or by hand for the purpose of varying the secondary voltage.

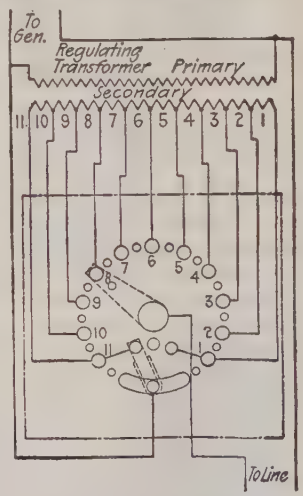


FIG. 39.—Single-phase, step-by-step type potential regulator.

74. The step-by-step potential regulator is merely a stationary transformer provided with a large number of secondary taps and equipped with a switching mechanism for joining any desired pair of these taps to the delivery circuit, according to the e.m.f. required. A diagram of the circuits of a regulator of this type is shown in Fig. 39. In comparison with the induction type of regulator the step-by-step type is less noisy in operation, requires less magnetizing current, and is more rapid in action. However, it provides only a limited number of voltage steps and may give trouble from arcing at the switch contacts.

CONNECTIONS—POLARITY

75. Polarity of Transformers.—The windings of a transformer are usually so connected to the leads extending out through the case that the direction of flow of the alternating current or the polarity of the transformer at any given instant is the same in all the corresponding leads of transformers of the same type.

Example.—The transformer of Fig. 40 is so connected internally that at an instant when current is flowing inwardly through the primary lead *A* it flows outwardly through the secondary lead *C*. The polarities of the single-phase transformers of practically all the large companies are as shown in Fig. 40. Where a transformer of a certain polarity is connected, without transposing its leads, in parallel with one of a different polarity the effect is the same as that of a short circuit on both units. Where such an incorrect connection has been made it can be corrected by reversing either the primary or the secondary leads.

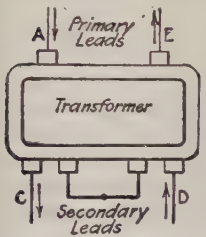


FIG. 40.—Standard instantaneous polarities.

76. The arrangement of the windings of a transformer does not necessarily determine its polarity. Polarity—so called—has to do only with the plan or arrangement adopted in bringing the leads out of the case. Interchanging the positions of the leads that extend through the bushings in the case will change the polarity of the transformer.

77. Tests for Polarity of Single-phase Transformers.—Where a standard transformer of known correct polarity and of the same ratio and voltage as the transformer to be tested is available, the following simple method can be used: Connect together (Fig. 41, I) the high-tension and the low-tension leads as if for parallel operation, inserting a fuse in one of the secondary leads. If both transformers are of the same polarity, no current will flow in the low-tension windings, and the fuse will not blow. If the transformers are of opposite polarities the low-tension windings will short-circuit each other, and the fuse will blow. The fuse should be sufficiently small so that there can be no possibility of injuring the transformers.

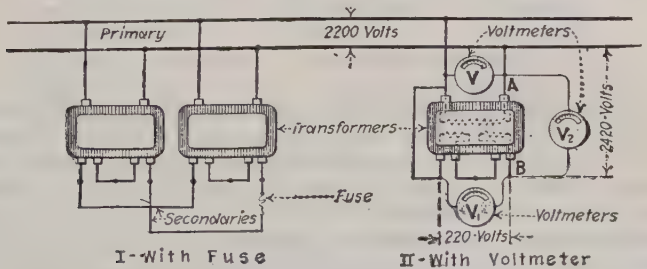


FIG. 41.—Testing transformers for polarity.

A method of testing for polarity of single-phase transformers with a voltmeter is shown in Fig. 41, II. Connect the transformer as shown. Make, successively, voltmeter readings V, V_1, and V_2. If the transformer has what is called additive polarity, $V + V_1$ will equal V_2. If the transformer has what is called subtractive polarity V_2 will equal $V - V_1$. For example, in Fig. 41, II the transformer has additive polarity, and the primary line voltage, V (2,200 volts) plus the secondary

transformer voltage V_1 (220 volts) equals the voltage between A and B, or 2,420 volts. With subtractive polarity the voltmeter V_2 would read (2,200 − 220) 1,980 volts.

SINGLE-PHASE CONNECTIONS

78. Connections for standard distribution transformers are shown in Figs. 42 and 43. Distribution transformers of medium and small capacity are almost invariably arranged with two secondary coils, which may be connected in series or parallel with each other so that the same transformer may be used to supply either of two different secondary voltages, or a three-wire system. In transformers of the 120/240-volt type their secondary windings can be so connected as to deliver 120 or 240 volts or for a 120/240-volt, three-wire circuit. The connections of the secondary coils are made, either by splicing the secondary leads or with connectors,

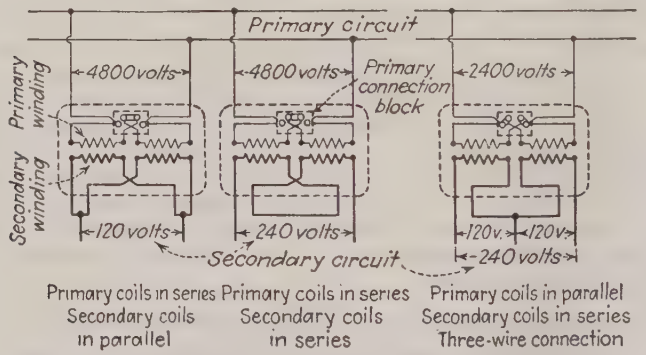


FIG. 42.—Connections of standard distributing transformers.

outside the transformer case. Some transformers are constructed with two primary coils as shown in Fig. 42. By making the necessary primary-coil connections, they may be used on primary circuits of either of two voltages. Standard practice with respect to number of coils and voltage ratings is given in Secs. **36** and **37**.

79. Transformer connections for three-wire secondary service are shown in Figs. 42, 43, and 44. In the arrangement Figs. 42 and 43, one transformer only is used. Its secondary windings are connected in series, and a tap is made to the point of connection between the two windings, providing 240 volts between the two outside wires and 120 volts on each of the side circuits. The transformer should have a capacity equal to the load to be supplied, and the three-wire circuits should be carefully balanced. If the three-wire circuits are decidedly unbalanced, the transformer should have a capacity equal to twice the load on the most heavily loaded of the two side circuits.

In Fig. 44, two transformers are shown connected to serve a three-wire circuit. The three-wire load should be balanced as nearly as possible, and where it is very nearly balanced each transformer should have a capacity equal to one-half of the total load. If the load is badly unbalanced, each transformer should have a capacity equal to the load on its side of the circuit. See discussion of Parallel Operation.

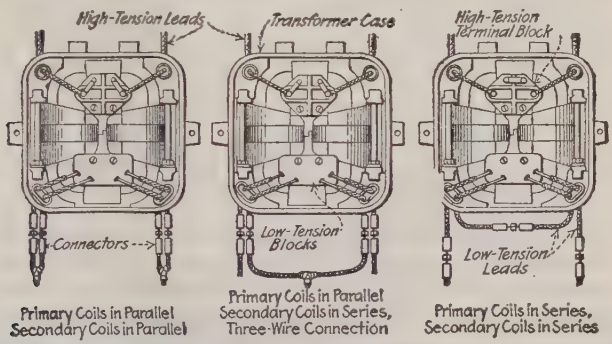


Fig. 43.—Method of interconnecting transformer secondaries with connectors.

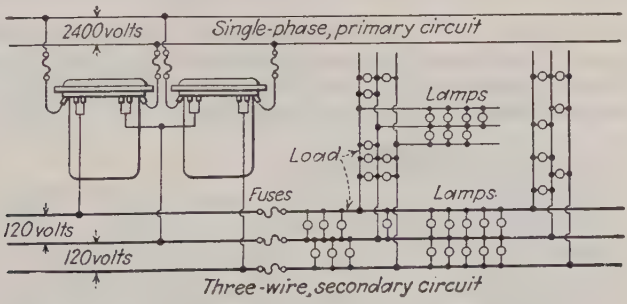


Fig. 44.—Two transformers serving a three-wire circuit

TWO-PHASE CONNECTIONS

80. Transformers connected to four-wire, two-phase circuits are shown in Fig. 45. As a rule, two-phase primary lines are four wire as shown, and to such a four-wire line the transformers are connected to each of the side circuits, as if each side circuit were a single-phase circuit not having any connection with the other. The total load should be so divided between the phases that the loads on each will be equal as nearly as possible. Each transformer should be designed for line voltage and will carry line current. Each transformer should have a kilovolt-ampere capacity equal to one-half of the kilovolt-ampere load that is served by the two transformers.

81. Transformers connected to three-wire, two-phase circuits are shown in Fig. 46. The current in the center line wire *AA* for balanced load is 1.41 times the current in either of the outer wires. Each transformer has line voltage impressed on it and carries one-half the total load.

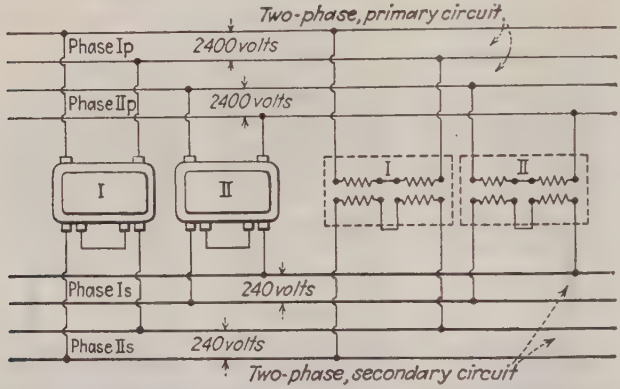


FIG. 45.—Transformers, two-phase to two-phase, four-wire connection.

A General Electric Co. publication comments thus: "Considerable unbalancing of voltage at the end of a transmission line or cable is experienced with the three-wire, two-phase system owing to the mutual induction between phases. Where the power factor is low, a still worse

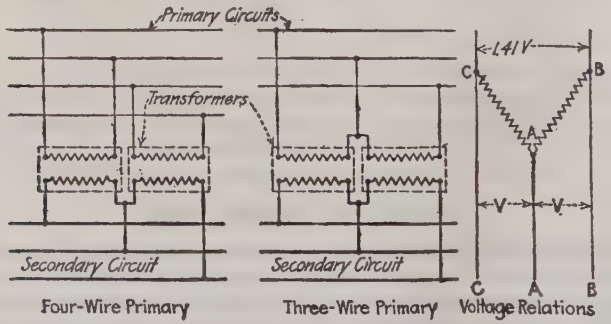


FIG. 46.—Connections for transformers on three-wire, two-phase circuits.

regulation is obtained, making satisfactory operation difficult. Very few systems now operate on this plan, and practically all of them could be improved by the use of some other system."

82. Mixed connections are sometimes made with two-phase transformers as shown in Fig. 47. With improper connections such as those

shown, difficulty will be experienced in the operation of motors and they may not run at all.

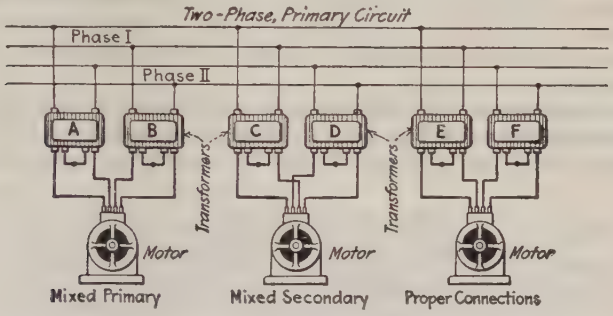


FIG. 47.—Correct and incorrect connections for transformers serving two-phase motors.

THREE-PHASE CONNECTIONS

83. Comparison of one three-phase transformer as against a group of single-phase transformers ("Standard Handbook") that may be employed for obtaining the same service has been summed up by J. S. Peck as follows: Advantages of three-phase transformer: (1) lower cost,

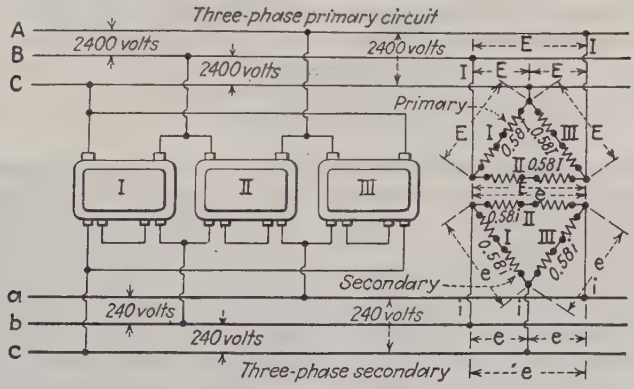


FIG. 48.—Transformers, delta-connected on both primary and secondary on three-phase circuits.

(2) higher efficiency, (3) less floor space and less weight, (4) simplification in outside wiring, and, (5) reduced transportation charges and reduced cost of installation. The disadvantages of the three-phase transformer are: (1) greater cost of spare units, (2) greater derangement of service in the event of breakdown, (3) greater cost of repair, (4) reduced capacity obtainable in self-cooling units, and (5) greater difficulties in bringing

out taps for a large number of voltages. It is considered that the three-phase transformer has certain real and positive advantages over the one-phase type, while its disadvantages are chiefly those which result in the event of breakdown—an abnormal condition which occurs at rarer and rarer intervals as the art of transformer design and manufacture advances.

84. Transformers with both primary and secondary coils delta (Δ) connected are shown in Fig. 48. All three of the transformers are connected in series in a closed circuit, and each line wire is connected to the

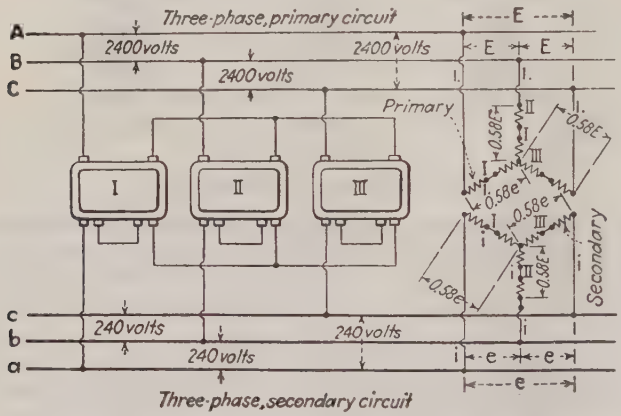


FIG. 49.—Transformers, star-connected on both primary and secondary on a three-phase circuit.

connection between two of the transformers. The voltage imposed on either the primary or secondary of the transformer is the primary or secondary line voltage, respectively. The current in either winding = line current $\div \sqrt{3}$, or line current $\times$ 0.58. The kilovolt-ampere capacity of each transformer should be equal to one-third the total kilovolt-amperes of the load to be served. The total kilovolt-ampere load transmitted by a balanced three-phase line = $1.73IE$ (where I is the line current in each line wire and E is the voltage between wires). Therefore, the kilovolt-ampere capacity of each transformer should be $1.73IE \div 3 = 0.58\ IE$.

85. Transformers with both primary and secondary coils, star connected, from a three-wire primary circuit, are shown in Fig. 49. The current in each transformer winding is the same as the line current, and the voltage imposed on each winding = line voltage $\div \sqrt{3}$ = line voltage $\times$ 0.58. The kilovolt-ampere capacity of each transformer should be equal to one-third the total kilovolt-amperes of the load to be served. The total kilovolt-ampere load transmitted by a balanced

three-phase line = $1.73IE$ (where I is the line current in each line wire and E is the voltage between wires). Therefore, the kilovolt-ampere capacity of each transformer should be $1.73IE \div 3 = 0.58IE$.

The star-star connection is seldom used.

The same grouping except that the primary circuit is four wire is shown in Fig. 50. In thus connecting transformers from a four-wire primary circuit it should be remembered that each right-hand primary terminal connects with a line wire and each left-hand terminal connects with the neutral wire or the reverse, respectively. The voltage and current relations are shown in the illustration.

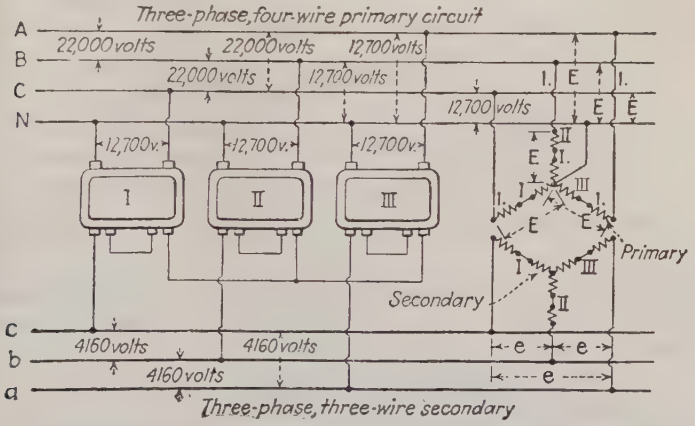


FIG. 50.—Transformers, star-connected on both primary and secondary on three-phase circuits (four-wire primary circuit).

Transformers which are star-star connected will have a strong third harmonic present in their secondary voltage. This voltage would produce a considerable flow of charging current from lines to ground, which would result in inductive disturbances. In order to eliminate this effect, transformers connected in this manner should be provided with an auxiliary secondary winding on each phase, called tertiary windings. The tertiary windings are connected into a closed delta. Sometimes the tertiary windings are used to supply some active load as well as provide the correction of the third harmonic.

86. Transformers delta-connected to the primary circuit and star-connected to the secondary circuit are shown in Fig. 51. Any group of transformers can have either their primary or secondary coils connected in either star or delta. With the primary delta-connected and the secondary star-connected as shown, the secondary voltage will be 1.73 times what it would be if it were delta-connected. For example, in the illustration (the transformers are assumed to have a 5.5:1 ratio) with a delta secondary connection the secondary line voltage would be 13,200

$\div 5.5 = 2{,}400$ volts, but with a star or Y secondary connection the secondary voltage is $2{,}400 \times 1.73 = 4{,}160$ volts. It should be noted that with a delta-connected primary an increase of 15 per cent in the

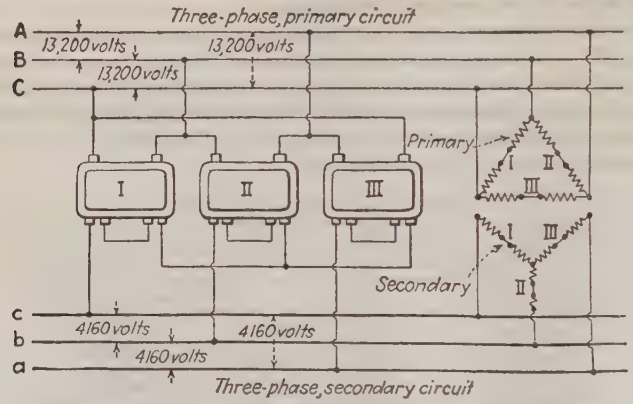


FIG. 51.—Transformers, delta-connected, primary and star-connected secondary.

primary voltage and a star secondary connection will make the secondary voltage twice what it would be with delta connection and normal primary voltage.

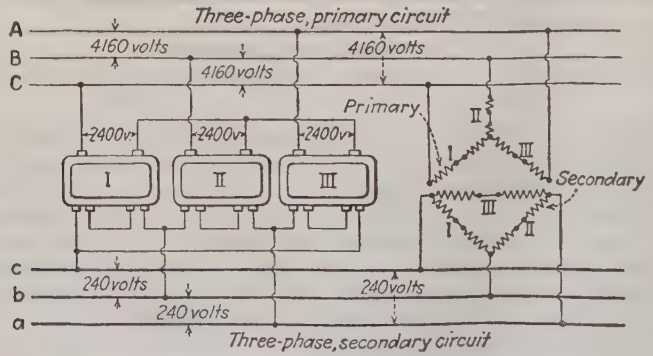


FIG. 52.—Transformers, star-connected primary and delta-connected secondary.

87. Transformers star-connected primary and delta-connected secondary are shown in Fig. 52. This is the reverse of the grouping described in Sec. **86,** and the secondary voltage will be but 0.58 times as great as if both secondary and primary were star-connected. The transformers shown have a ratio of 10:1.

88. The Three-phase V or Open-delta Connection (Figs. 53 and 54).—Line voltage is impressed on each transformer, and line current flows in each transformer coil. This method is considerably used for motors but has the objection that if one of the transformers becomes inoperative the three-phase circuit served will be fed by but one transformer and hence will be inoperative. (The reversed-V connection is indicated at the primary side in Fig. 54.)

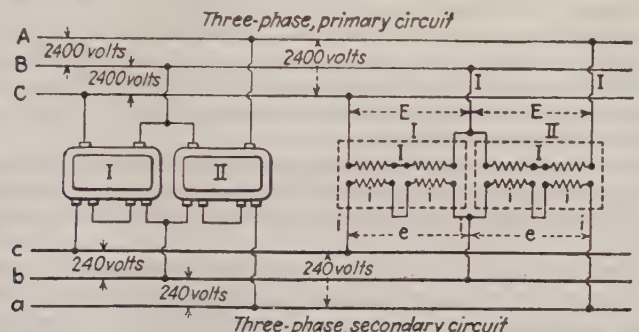


Fig. 53.—Transformers, V- or open-delta primary and secondary (three-wire, three-phase primary circuit and three-wire, three-phase secondary circuit).

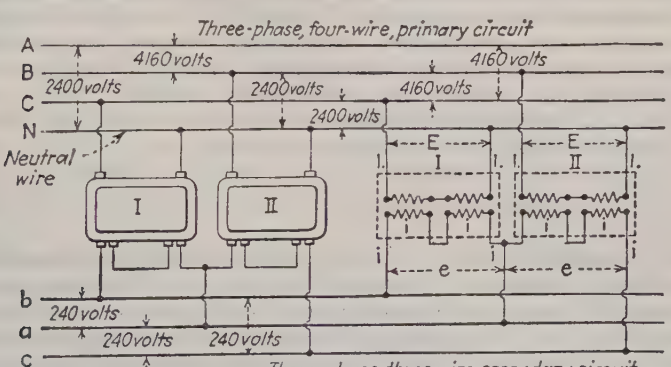


Fig. 54.—Transformers, primary-connected in reversed-V and secondary V-connected (four-wire, three-phase primary circuit and three-wire, three phase secondary circuit).

The combined capacity of two transformers (Gear and Williams) connected by this method and serving a given load should be 15.5 per cent greater than the combined capacity of three transformers delta or star connected and serving the same load. For instance if three 5-kva. transformers (total capacity 15 kva.) are required for a certain installation and they are replaced by two 7½-kva. transformers (total capacity

15 kva.), the two transformers will be overloaded by 15.5 per cent at a full load of 15 kw. at 100 per cent p.f.

For example, assume that in a three-transformer installation the current in the secondary line is 17.3 amp. This imposes a load of 10 amp. on the transformer secondary coils. At 200 volts this is 2 kw. per transformer or 6 kw. in all. If two 3-kw. transformers are put in to replace the three 2-kw. units, the capacity of the secondary coils would be 15 amp. But, as above noted, with the open-delta connection the current in the secondary coil is the same as the current in the line, and the 15-amp. winding must carry 17.3 amp. or 15.5 per cent overload.

In the grouping of Fig. 53, to reverse the direction of a motor served by the group, interchange any two of the primary phase wires or reverse any two of the secondary wires.

In some cases two transformers for open-delta grouping of proper aggregate capacity to serve a given load will be cheaper than three transformers for star or delta grouping to serve the same load, but this is not always the case.

89. Disadvantages of the V or Open-delta Connection ("Standard Handbook").—For normal operation not only must each of the V-connected transformers be larger than each of the delta-connected transformers, but the two transformers must have a combined rating 15.5 per cent greater than the three transformers. This fact taken alone does not represent a disadvantage of the V-connection, because the two larger transformers are exactly equal in constructive material and operating efficiency to the three smaller transformers. The real objection to the V-connection for serious work resides in the tendency for the local impedance of the transformers to produce an enormous unbalance of the secondary voltages and of the primary currents. In spite of this disadvantage (which is really of little consequence in 2,200-volt primary, distribution work) many V-connected groupings are in satisfactory operation.

90. Comparison between the Delta, the Star, and the Open-delta Methods of Connection ("Standard Handbook").—The choice between the methods would be governed largely by the service requirements. When the three transformers are delta-connected one may be removed without interrupting the performance of the circuit—the two remaining transformers, in a manner, acting in series to carry the load of the missing transformer. The desire to obtain immunity from a shut-down due to the disabling of one transformer has led to the extensive use of the delta connection of transformers, especially on the low-potential delivery side. It is to be noted that in case one transformer is crippled the other two will be subjected to greatly increased losses.

Thus, if three delta-connected transformers be equally loaded until each carries 100 amp., there will be 173 amp. in each external circuit wire. If one transformer be now removed and 173 amp. continue to

be supplied to each external circuit wire, each of the remaining transformers must carry 173 amp., since it is now in series with an external circuit. Therefore, each transformer must now show three times as much copper loss as when all three transformers were active, or the total copper loss is now increased to a value of six relative to its former value of three. An open delta installation is made frequently where considerable future increase in load is expected. The increase can be accommodated by adding the third transformer to the bank at a later date and thus increasing the capacity of the load that can be carried by about 75 per cent.

A change from delta to Y in the secondary circuit alters the ratio of the transmission e.m.f. to the receiver e.m.f. from 1 to $\sqrt{3}$. On account of this fact, when the e.m.f. of the transmission circuit is so high that the successful insulation of transformer coils becomes of constructive and pecuniary importance, the three-phase line sides of the transformers are connected in "star" and the neutral is grounded. The windings of most transformers operating on systems of 100,000 volts or more are star connected.

See also Sec. 89 regarding properties of an open-delta connected group.

91. Comparative Cost of Transformers for Different Grouping for Three-phase Service.—The following table shows the costs in 1930 of the single-phase transformers, of proper capacities for either a delta or an open-delta grouping and of a three-phase transformer to serve a 75-kva. installation. The relative costs will be the same for the present date.

Method of connection or grouping	Number of transformers required	Capacity of each transformer, kva.	Aggregate capacity	Cost per transformer	Aggregate cost
Delta (Δ)	3	25	75	$317	$951
Open Delta (V)[a]	2	50	100	522	1,044
Three-phase transformer	1	75	75	950	950

[a] The theoretical aggregate capacity of two single-phase transformers for open-delta grouping for a 75-kva. three-phase load would be (see 88): $75 \times 1.15 = 86.3$ kva. or $86.3 \div 2 = 43.2$ kva. per transformer. The nearest commercial capacity to 43.2 kva. is 50 kva., which gives an aggregate capacity of 100 kva.

92. Polarity of Single-phase Transformers Connected in Banks on Three-phase Circuits (W. M. McConahey, *Electric Journal*).—A standard star-delta connection with six single-phase transformers is shown in Fig. 55. The polarity of No. 6 is the reverse of that of the other five. If the polarity of all six transformers were the same, No. 6 would be connected in a manner similar to that of No. 3 instead of having the connections of one winding reversed. If the polarity of all the transformers is the same, all banks should be connected to the line in exactly the

same manner. It is possible to connect one bank differently from the others, and still secure parallel operation, but this is not advisable,

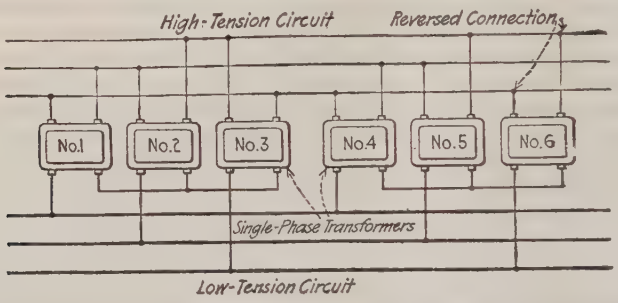


FIG. 55.—Single-phase transformers connected in a bank on a three-phase circuit.

because it is apt to lead to confusion and trouble. It is best to adopt one scheme of connection and to adhere to it.

SPECIAL TRANSFORMER CONNECTIONS

93. Transformers connected for transforming from three-phase to two-phase or the reverse are illustrated in Fig. 56, which shows what is

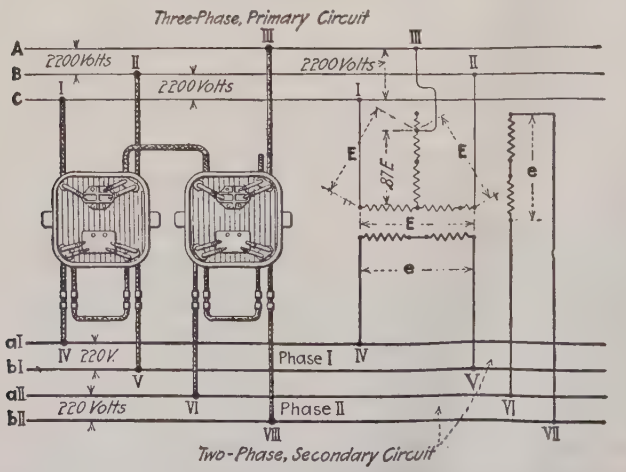


FIG. 56.—Transformers connected for three-phase to two-phase transformation.

known as the Scott connection. The transformers required are special, and each has a lead brought out from the middle point of the high-tension

winding, and a special voltage tap is arranged giving 86.6 per cent of the high-tension winding. Usually two transformers just alike are purchased so that they will be interchangeable. These special transformers can be purchased from any of the large manufacturers. Those shown are Westinghouse transformers. Two standard single-phase transformers for such service should have an aggregate kilovolt-ampere rating 15½ per cent greater than their group or nominal rating.

94. Explanation of the Transformation from Three-phase to Two-phase ("Standard Handbook").—Assume the simple case of a total power of 30,000 watts, 1.0 p.t., at 100 volts, three-phase, to be transformed (without loss) to 30,000 watts, 100 volts, two-phase (see Fig. 57). Assuming that the load is balanced on the two-phase side, there will be 15,000 watts per phase, or 150 amp. at 100 volts. Since the three-phase power is represented as $\sqrt{3}\,IE = 30{,}000$, where I is the current per line wire and E is the e.m.f. between line wires, I must equal 173.2 amp., because E has been taken as 100 volts.

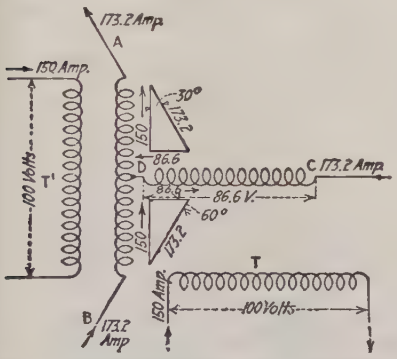


FIG. 57.—Three-phase to two-phase transformation.

As shown in Fig. 57, the three-phase coils of one transformer must be designed for 100 volts and 173.2 amp. while the three-phase coils of the other transformer must be designed for 86.6 volts and 173.2 amp. The current through the coil CD divides equally, a part (86.6 amp.) goes through DA and an equal part (86.6 amp.) passes differentially through DB; thus the m.m.f. of these two currents has a resultant of zero, and it has no effect upon the core flux so far as transformer T' is concerned. The coil ADB carries a total value of current of 173.2 amp. throughout all its turns, but the current in one half is 60 time degrees out of phase with that in the other half. That is to say the 173.2 amp. in one half is made up of a load current of 150 amp., in leading time quadrature with which is 86.6 amp., while that in the other half is made up of a load current of 150 amp., in lagging time quadrature with which is a superposed current of 86.6 amp. The magnetizing effect of the 173.2 amp. is, therefore, 150 amp., and the current in the two-phase side of transformer T' is 150 amp. In the T transformer the m.m.f. of 173.2 amp. in 86.6 per cent turns is just equal to that of 150 amp. in 100 per cent turns; these two currents are directly in time-phase opposition, and the apparatus operates in all respects like a one-phase transformer. The phase relations and the relative values of the several components of currents are shown in the vector diagram of Fig. 57.

95. Kilovolt-ampere Ratings of Transformers for Scott Connection (Three-phase to Two-phase) for Serving a Given Horsepower Load.—The following table gives the ratings recommended by the Westinghouse Electric & Manufacturing Co. for transformers serving squirrel-cage induction motors and indicates the efficiency of the installation. The temperature guarantee with performances as shown is a 50°C. rise.

Hp. of motor	Number of transformers	Kva. capacity of each transformer	Total kva. load imposed on the group of two transformers when motor is operating at full load	Efficiency of bank of transformers with full load on motor
½	2	½	0.75	92.8
1	2	½	1.35	94.5
2	2	1	2.40	95.2
3	2	1½	3.4	95.9
5	2	2½	5.5	96.4
7½	2	4	8.1	97.0
10	2	5	10.7	97.2
15	2	7½	15.7	97.4
20	2	10	20.9	97.6
30	2	15	31.5	97.8
40	2	20	42.0	98.0
50	2	25	51.0	98.0
75	2	37½	77.0	98.3

$$\text{Kva. on each transformer} = \frac{\text{hp.} \times 0.746 \times 0.59}{(\text{eff.} \times \text{p.f. of motor})}$$

$$\text{Efficiency} = \frac{\text{kw. on transformer}}{\text{kw. transformer loss} + \text{kw. on transformer}}$$

96. T-connected Transformers for Transforming from Three-phase to Three-phase ("Standard Handbook").—A method of employing two transformers in three-phase transformation which practically overcomes the disadvantages of the V connection, and possesses considerable merit, is found in the T connection. As indicated in Fig. 58, one transformer is connected across between two of the line wires while the other is joined between the third line wire and the middle point of the first transformer. The current in the primary coil of each transformer is the same in value as that in the primary coil of the other, and the secondary currents in the two transformers are likewise equal in value. The voltage impressed across one transformer is only 86.6 per cent of that across the other, so that, if each transformer is designed especially for its work, one will have a rating of EI and the other a rating of $0.866EI$, where I is the current in each line wire and E is the e.m.f. between lines. The

combined rating will therefore be 1.866 as compared with $1.732EI$ for three one-phase transformers connected either Δ or Y, or with $2.0EI$ for two V-connected transformers.

97. Requisites for Transformers for T Connection.—The two transformers should possess the same ratio of primary to secondary turns, and a tap should be brought out from the central point of one of the transformers. It is not essential that the former transformer be designed for exactly 86.6 per cent of the voltage of the latter; the normal voltage of one can be 90 per cent of the other without producing detrimental results. Moreover, transformers designed for the same normal e.m.f. and intended for V connection can be T-connected with considerable improvement in service.

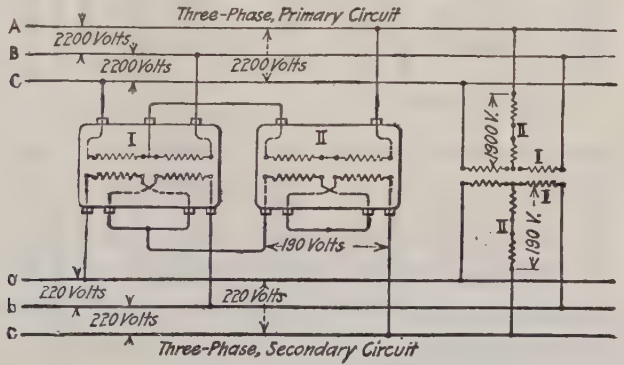


FIG. 58.—Transformers, T-connected for three-phase transformation.

98. In comparing the T connection with the Δ or the Y connection ("Standard Handbook"), it is to be noted that each connection accomplishes the transformation without sensible distortion of phase relations. The T connection allows the neutral point to be reached equally as well as does the Y connection. The Δ connection, however, is the only one capable of transforming in emergencies with one disabled transformer. With reference to its ability to maintain balanced phase relations, the T connection is much better than the V connection.

The aggregate kilovolt-ampere rating of two T-connected transformers should be 15½ per cent greater than the nominal kilovolt-ampere rating of the group.

99. Booster transformers ("Electric Central Station Distributing Systems," Gear and Williams, Van Nostrand Co.).—Ordinary distributing transformers applied as illustrated (Fig. 59) are used where it is necessary to raise, by a fixed percentage, the voltage delivered by a line, as is necessary when transformer ratios do not give quite the right voltage or when line drop is excessive. A booster raises the voltage of

any primary circuit in which it may be inserted by the amount of the secondary voltage of the booster (see Fig. 59).

Examples.—On a long, single-phase, 2,080-volt lighting branch so heavily loaded that the pressure drops more than the amount for which the normal regulation of the feeder will compensate, a 110-volt transformer inserted in the line as a booster will raise the pressure of the primary branch on the load side of the booster by 110 volts. This raises the secondary pressure 5.5 per cent on all the transformers beyond the booster.

With 440-volt service supplied by star-connected, 230-volt transformers, a 10 per cent booster in each phase raises the normal pressure of 230/400 volts to 253/440 volts.

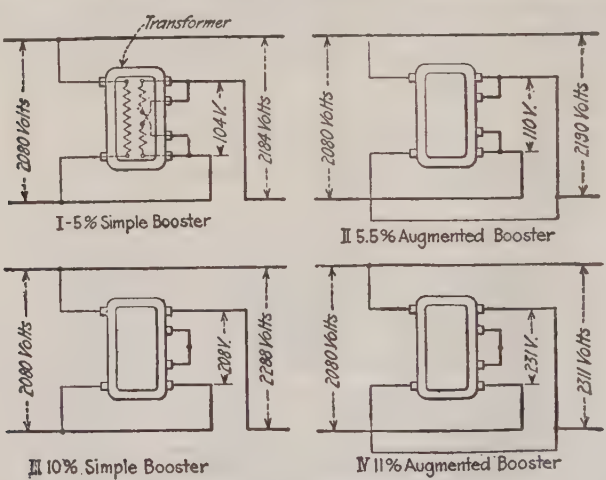


FIG. 59.—Transformers used as boosters.

The connections for a simple booster are shown in Fig. 59, I, the line pressure being raised from 2,080 to 2,184 volts or 5 per cent. The connection at II is that for an augmented booster in which the line pressure is raised from 2,080 to 2,190 volts, because the primary of the booster is connected across the line on the far side and the booster is boosted as well as the line. This gives an increase of 5.5 per cent in the line pressure.

Figure 59, III, shows a 10 per cent simple booster and IV an augmented 11.1 per cent booster.

The transformers shown in Fig. 59 have a 10:1 or 20:1 ratio, and the percentages shown apply only to transformers of this ratio. If boosters having a ratio of 2,080 to 115/230 are used, the percentages are increased by about 10 per cent. Figure 59 I would then become 5.5 per cent; II, 6.05 per cent; III, 11.1 per cent; and IV, 12.2 per cent.

100. The proper connection of the secondary for a booster or choke transformer must usually be determined by trial for a transformer of any given type, but, once it has been determined, the same connection may be used for any transformer of the same type. The connections shown in Figs. 59 and 60 are correct for transformers of the principal makers.

101. Boosters are connected in a two-phase circuit in a manner similar to that shown in Fig. 59 for a single-phase circuit. In three-wire, two-phase feeders the boosters (secondary windings) are cut into the outer

wires, and the primary windings are connected between the middle and the outside wires.

102. Booster transformers in three-phase circuits are connected as shown in Fig. 61 ("Electric Central Station Distributing Systems"). The insertion in any phase wire of the booster voltage affects two phases.

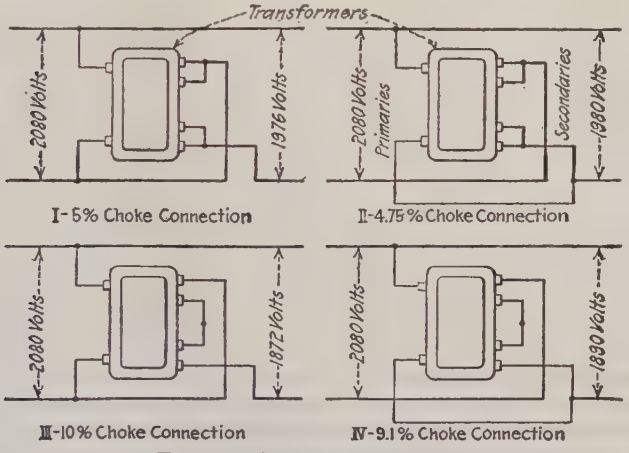


FIG. 60.—Choking transformers.

The boosting and choking effects, with transformers of various ratios, with the boosting transformers used in one, two, or three phases, are expressed in percentage of the primary voltage in the table of Sec. **103.**

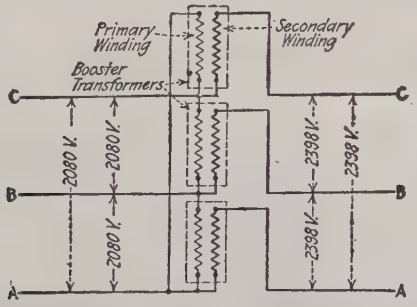


FIG. 61.—Booster transformers in a three-wire, three-phase circuit.

103. Voltage Boosting and Choking Effect of Transformers Connected in Three-phase Circuits ("Electric Central Station Distributing Systems").—Values in the body of the tables are the percentages that the voltages will be increased or decreased, respectively, by the insertion of booster or choking transformers, of different ratios, in one, two, or three

of the phase wires. Transformers are connected for boosting as shown in Fig. 61. The letters *AB*, *BC*, and *CA* refer to the three phases of Fig. 61.

Boosting

Ratios	10:1			20:1			9:1			18:1		
Booster in	*AB*	*BC*	*CA*	*AB*	*BC*	*CA*	*AB*	*BC*	*CA*	*AB*	*BC*	*CA*
A phase	10.0	10.0	5.3	5.00	0.00	2.65	11.0	0.0	5.8	5.5	0.00	2.9
A and *B*	15.3	10.0	5.3	7.65	5.00	2.65	16.8	5.5	5.8	8.4	2.75	2.9
A, *B*, and *C*	15.3	15.3	15.3	7.65	7.65	7.65	16.8	16.8	16.8	8.4	8.40	8.4

Choking

A phase	10.0	0.0	4.6	5.0	0.0	2.3	11.00	0.00	5.06	5.5	0.00	2.53
A and *B*	14.6	10.0	4.6	7.3	5.0	2.3	16.06	11.00	5.06	8.3	5.50	2.53
A, *B*, and *C*	14.6	14.6	14.6	7.3	7.3	7.3	16.06	16.06	16.08	8.03	8.03	8.03

104. Choking Transformers ("Electric Central Station Distributing Systems").—When the secondary is connected in reverse order the transformer becomes a "choke," depressing the line pressure instead of raising it. This method of connection is useful where less pressure is desired.

Examples.—A 5 per cent choke connection is shown in Fig. 60, I, a 4.75 per cent choke in II, a 10 per cent choke in III, and a 9.1 per cent choke in IV.

The transformers shown in Fig. 60 have a ratio of 10:1 or 20:1, and the percentages shown are only for transformers of that ratio. If choking transformers having a ratio of 2,080 to 115/230 are used, the choking percentages would be decreased to the following values: Fig. 60, I, 5.5 per cent; II, 5.24 per cent; III, 11 per cent; and IV, 10 per cent.

105. The capacity of a transformer that is to be used as a booster (Fig. 62) will be determined by (1) the current *I* which will flow in the

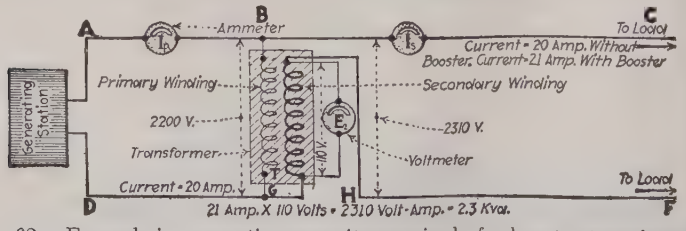


FIG. 62.—Example in computing capacity required of a booster transformer.

a-c line, and (2) the voltage *E* by which the e.m.f. on the line will be "boosted." If, for example, the current in the line is 20 amp. and it is desired to raise the voltage (Fig. 62) by 110 volts, then required capacity of the boosting transformer = 20 amp. × 110 volts = 2,200 volt-amperes

= 2.2 kva. Hence, for these conditions it would be necessary to use at I a standard 2½-kva. transformer. The secondary coils of this transformer would be connected in multiple so that they would develop 110 volts.

If it is desired to boost the voltage by 220 volts, then 20 amp. × 220 volts = 4,400 volt-amperes = 4.4 kva. Hence, theoretically a 4.4-kva. transformer would be required. Note that in any case the secondary winding of the boosting transformer must be capable of carrying the primary line current (20 amp., in Fig. 62). Furthermore, the secondary coils of the boosting transformer must be so designed and connected that they will produce at their terminals the voltage by which it is desired to "boost" the e.m.f. which is impressed on the line by the generator in the station.

106. As a practical proposition it is usually desirable to select for the "boost" voltage one of the voltages for which the secondaries of distributing transformers are regularly designed or for which they can be connected. That is, the boosting voltage should, ordinarily, be either 110, 220, or 440. If a boosting voltage other than one of these standard voltages is necessary, it will then probably be necessary to obtain a specially designed transformer or to obtain a transformer which has taps on the secondary coils.

107. In every case the line current will be increased somewhat by the boosting transformer. If the load remains constant, the increase in that portion of the circuit *HFCB* (Fig. 62) will be in the ratio by which the voltage impressed on this portion of the circuit has been boosted. For example, if the current in the a-c line *HFCB* of Fig. 62 was 20 amp. before the boosting transformer was inserted, the current after its insertion would be computed in this way:

$$\frac{I_2}{I_1} = \frac{E_2}{E_1} \tag{3}$$

$$I_2 = \frac{E_2 \times I_1}{E_1} \quad \text{(amperes)} \tag{4}$$

where I_1 = the line-current, in amperes, before inserting the booster transformer; E_1 = e.m.f., in volts across *BH* (Fig. 62) before inserting the booster transformer; I_2 = current, in amperes, in *HFCB* after the booster is inserted; and E_2 = e.m.f., in volts, across *BH* after the booster is inserted.

Example.—Substituting the values from Fig. 62 in For. (4), the current in *HFCB* after inserting the booster = $I_2 = (E_2 \times I_1) \div E_1 = (2{,}310 \times 20) \div 2{,}200 = 21$ amp. After inserting the booster, the current I_p in *ABGD* will be (21 amp. + the current carried by the primary winding). The value of 20 amp. in Sec. 105 is not strictly correct, but this relatively small difference will not appreciably affect the kilovolt-ampere rating of the booster transformer which would be used.

108. There are certain precautions that should be observed in the installation of boosters ("Electric Central Station Distributing Systems")

to protect them from injury. The booster secondary is in series with the line, and current is drawn through its primary windings in proportion to the load on the line. If the primary of the booster is opened while the secondary is carrying the line current the booster acts as a choke coil in the main circuit. This causes a large drop of pressure in the booster, imposing upon its secondary windings a difference of potential of two to five times normal. Under these conditions the insulation of a 2,000-volt transformer may be subjected to a pressure of 10,000 to 20,000 volts or more depending upon the load carried by the main circuit at the time.

If a fuse is used in the primary its blowing creates the above condition, and the arc holds across the terminals of the fuse block until it burns itself clear. It has often been observed that where boosters have been "protected" by fuses in this way, the transformer has burned out shortly after the blowing of its primary fuses if not at the time.

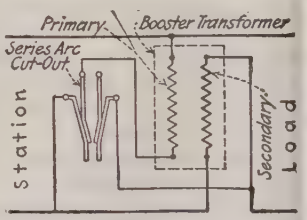


FIG. 63.—Series arc cutout for a booster.

Also, in using ordinary static transformers as boosters, it should be remembered that the service is different from that for which the transformer is designed. If this feature is neglected, the insulation may be subjected to excessive voltages or dielectric stresses, thus causing breakdown. The standard distributing transformer is designed to withstand a pressure of about 10,000 volts between the high-voltage coils and the case, while the low-voltage coils (the 220-volt coils) are designed to withstand a test pressure of 4,000 volts between coils, core, and case for a period of 1 min.

When a 2,200–110/220-volt transformer is used as a booster, the low-voltage coils are subjected to a continuous pressure of about 2,300 volts above ground. This sustained voltage will, if the case is grounded, be likely to destroy the insulation of the low-voltage coils. Therefore the transformer case should, if feasible, be insulated from the ground, although this may involve life hazard. When installed on a pole, the insulation is automatically provided since the pole acts as the insulating medium.

In transformer vaults and houses, the transformers are frequently placed upon the floor. Where static transformers are used as boosters, they should, to ensure safety to both the apparatus and workmen, be placed upon a slightly raised platform of dry wood. In any installation where apparatus such as the oil-cooled transformer is operating at or slightly above full load, the capacity will be increased if they are raised above the floor level. This permits free air circulation along the bottoms of the apparatus, thus further augmenting the dissipation of the heat. To ensure that the capacity of the booster will be sufficient, it should be also remembered that the load factor on a booster will usually be

higher than it would in ordinary service as a distribution transformer. These and other causes, if neglected, frequently result in the burnout or insulation breakdown of booster transformers.

109. Booster Cutout (Gear and Williams).—In connecting or disconnecting a booster the main line should be opened before putting it in or out. If service on the line cannot be interrupted, or if it is desired to switch the booster in or out at certain times, it may be done with a series arc cutout as in Fig. 63. The operation of the cutout simultaneously

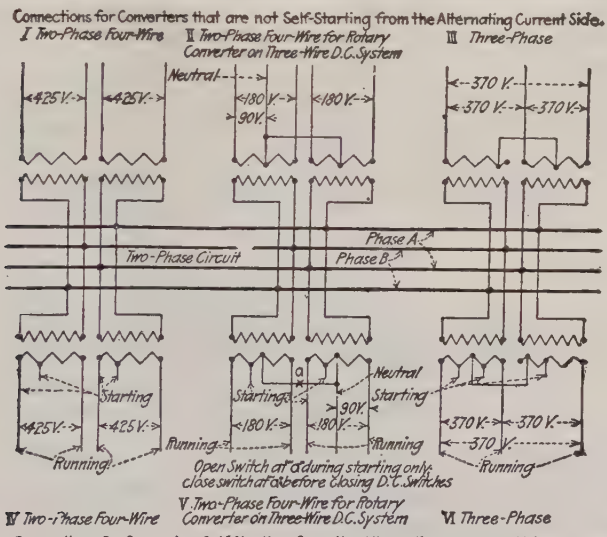


FIG. 64.—Connections for transformers serving rotary converters from a two-phase system. (*Westinghouse Electric & Manufacturing Co.*)

opens the primary and short-circuits the secondary of the booster. The switch must be of a type having a positive action so that arcing will not damage its contacts at the moment the secondary is short-circuited. The arc cutout must have sufficient carrying capacity to carry the main-line current when the booster is shunted out, and standard series cutouts should not be used where the line current is likely to exceed 20 to 25 amp.

When the augmented booster is used, the terminals of the primary winding of the transformer which goes to the cutout should be connected to the terminal of the cutout which is shown as not being in use in Fig. 63.

110. Transformers for serving rotary converters may be connected as indicated in Figs. 64 and 65, which show Westinghouse standard practice.

The secondary voltages given are (with four exceptions) the ones that should be impressed on the a-c sides of converters so that the converters will produce a d-c voltage of 600 for railway work. The four exceptions are noted in the illustrations.

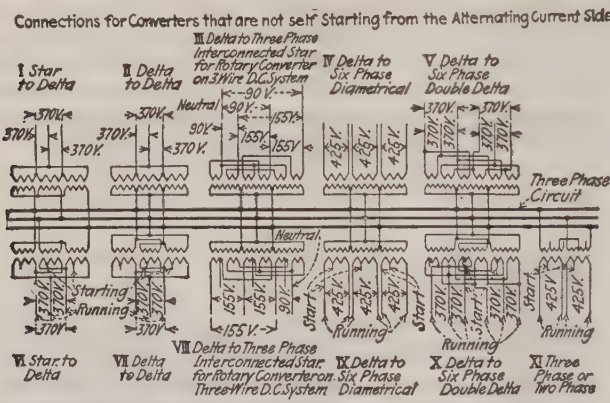


FIG. 65.—Connection for transformers serving rotary converters from a three-phase system. (*Westinghouse Electric & Manufacturing Co.*)

CONNECTIONS FOR THREE-PHASE TRANSFORMERS

111. Methods of Connecting the Windings of Three-phase Transformers ("Standard Handbook").—The windings of each component transformer are connected to the external circuits just as though this component were a one-phase unit; *i.e.*, the primaries may be connected either Y or delta. Moreover the relative advantages of the Y connection and the delta connection are quite the same with one three-phase transformer as with three one-phase transformers. The delta connection is advantageous in some cases in that if the windings of one phase become damaged by short circuiting, grounding, or through any other defect, it is possible to operate with the other phase windings V-connected.

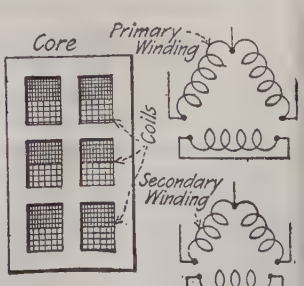


FIG. 66.—Operating a damaged three-phase transformer.

112. In operating a damaged three-phase transformer on two coils it is necessary to separate the damaged transformer windings electrically from the other coils, as indicated in Fig. 66. The high-potential winding

of the damaged phase should be short-circuited upon itself and the corresponding low-potential winding should also be short-circuited upon itself. The winding thus short-circuited will choke down the flux passing through the portion of the core surrounded by them without producing in any portion of the winding a current greater than a small fraction of the current which would normally exist in such portion at full load.

PARALLEL OPERATION

113. Parallel Operation of Transformers.—Transformers will operate satisfactorily in parallel (Fig. 67), *i.e.*, with their high- and low-tension windings respectively connected directly to the same circuits provided that they have (1) the same ratio of transformation, (2) the same voltage ratings, and (3) approximately the same regulation. If the low-tension voltages are different the transformer having the highest voltages will circulate current to those of lower voltage and cause a continuous loss.

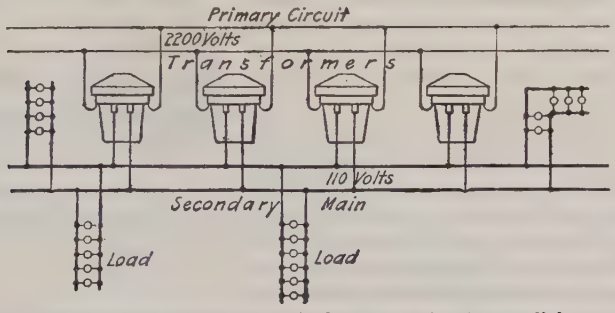


FIG. 67.—Transformers banked or operating in parallel.

If transformers connected in parallel do not have the same regulation they will not share the total load in proportion to their ratings. The greater share of the load will be taken by the transformer having the best regulation.

In connecting large transformers in parallel, especially when one of the windings is for a comparatively low voltage, it is necessary that the resistance of the joints and interconnecting leads does not vary materially for the different transformers, or it will cause an unequal division of load.

114. With transformers of the same general voltage and capacity characteristics connected in multiple in a secondary network ("Distributing Transformers," A. D. Fishel) little trouble will be encountered, as the impedance of the line between two transformers on separate poles spaced about 100 or 200 ft. apart will normally neutralize any difference in the transformer impedances. When transformers operated in multiple are placed on the same pole the question of equal sharing of the load may

be of some importance. The standard transformers of reliable manufacturers do not differ very widely in impedance characteristics, however, and it is usually practicable to operate transformers of the various standard types in parallel. Often the commercial desirability of paralleling transformers of different sizes will overbalance the undesirability of some inequality in the sharing of the load which might result.

115. A method of forcing equal division of load between transformers having considerably different impedance characteristics ("Distributing Transformers," A. D. Fishel), is shown in Fig. 68. Standard, 2,200-volt distributing transformers are usually provided with arrangements for the series-parallel connecting of both the high-tension and the low-tension windings, and therefore the connections shown can be used. As the high-tension windings are in series, the currents in the primary windings will be the same; hence the transformers will be equally loaded.

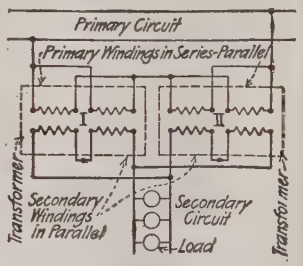


FIG. 68.—Connection for forcing parallel operation of transformers which have different impedance characteristics.

116. Some three-phase transformers can be paralleled and some cannot (W. M. McConahey, *Electric Journal*, July, 1912). A transformer having its coils connected in delta on both high-tension and low-tension sides cannot be made to parallel with one connected either in delta on the high-tension and star on the low-tension or in star on the high-tension and in delta on the low-tension side. However, a transformer connected in delta on the high-tension and in star on the low-tension side can be made to parallel with transformers (having their coils joined in accordance with certain schemes) connected in star on the high-tension side and in delta on the low-tension side. Some three-phase transformers cannot be made to parallel (without changing the internal connection arrangement of their coils) with others using the same type of connections for the two windings. For example, a transformer connected delta to delta may have its coils so interconnected that it will not parallel with another transformer connected delta to delta. By changing the internal connections between the coils, however, it will be possible to bring out the terminals in such a way that parallel operation can be obtained.

117. How to Determine Whether or Not Three-phase Transformers Will Operate in Parallel.—If the transformers are available connect them as indicated in Fig. 69, leaving two leads on one of the transformers unjoined. Test with a voltmeter across the unjoined leads. If there is no voltage between E and e or between F and f of transformer 2 the polarities of the transformers are the same, and the connections can be completed and the transformers put in service.

If a voltage difference is found between E and e or between F and f or between both, the polarities of the transformers are not the same. Then connect transformer lead A successively to mains 1, 2, and 3 and at each connection test with the voltmeter between e and f and the legs of the main to which lead A is not connected. If with any trial connection the voltmeter readings between f and e and either of the two legs is found to be zero, the transformer will operate with leads f and e connected to those two legs. If no system of connections can be found that will satisfy this condition, the transformer will not operate in parallel without changes in its internal connections, and it may be that it will not operate in parallel at all (see Sec. **116**).

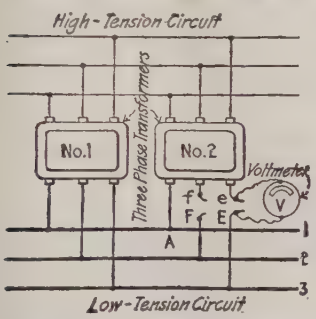


FIG. 69.—Testing three-phase transformers for parallel operation.

For a very complete discussion of this subject and the description of a method whereby it can be determined by voltmeter tests whether or not two three-phase transformers which cannot be brought together for a practical test will or can be made to operate in parallel, see article in *Electric Journal* for July, 1912, by W. M. McConahey. The above material is largely abstracted from this article.

CONNECTIONS AND APPLICATIONS OF AUTOTRANSFORMERS

118. Use of Autotransformers.—The National Electrical Code allows the use of autotransformers for supplying interior wiring systems under certain conditions. The principal application for lighting circuits is for 115/230-volt lighting secondaries on which the starting of fractional-horsepower, single-phase, 115-volt motors causes too much voltage drop on the secondary main, and flicker of the lights results. The installation of an autotransformer at the end of the main (Fig. 70) helps to reduce the voltage drop and materially reduces the flicker.

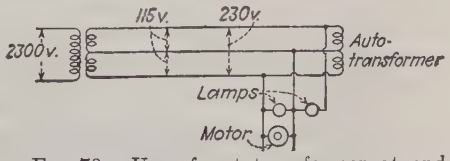


FIG. 70.—Use of autotransformer at end of main to improve voltage drop and reduce flicker.

119. Another application of the autotransformer is as a starting compensator for a-c motors. The compensator supplies a reduced voltage to the motor circuits while the machine is accelerating from rest. Ordinarily each autotransformer is provided with several taps so that a number of low voltages may be obtained.

120. A starting compensator arrangement for a two-phase induction motor ("Standard Handbook") is shown in Fig. 71. There are two autotransformers, the two separate phase lines being connected to the ends of the separate autotransformer windings. During the starting period the motor is connected between two of the ends and two intermediate taps. Figure 72 shows a starting compensator arrangement for a three-

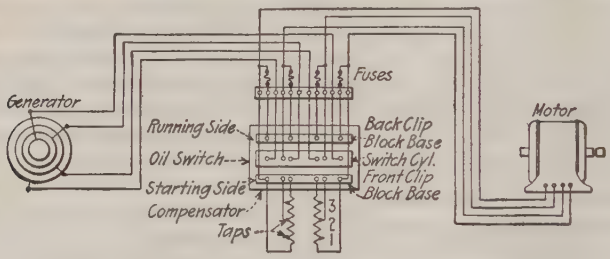


FIG. 71.—Two-phase starting compensator.

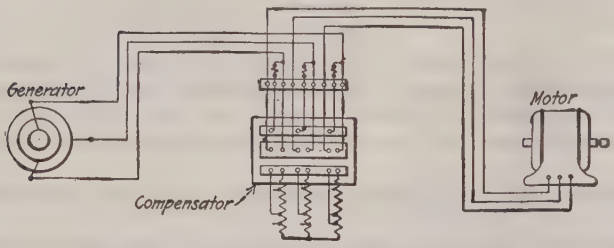


FIG. 72.—Three-phase starting compensator.

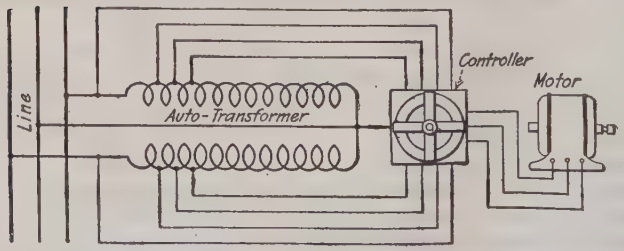


FIG. 73.—An autotransformer, three-phase, starting compensator.

phase induction motor. The three autotransformer windings are Y-connected, and low-voltage points are permanently selected along each leg of the Y. It is not necessary to employ three autotransformers for starting a three-phase motor; two V-connected autotransformers are quite satisfactory for this purpose. Figure 73 shows two V-connected autotransformers for starting a three-phase induction motor and operating it at four different voltages.

121. The coils of a three-phase transformer can be connected for operation as an autotransformer, equally as well as can those of a one-phase transformer. The interconnections would ordinarily be by the Y method, although the delta method or a combination of the Y and delta methods may be used. Figure 74 represents a Y connection for autotransformer operation.

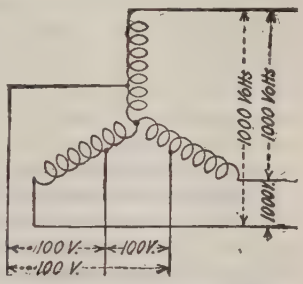


FIG. 74.—Y-connected, three-phase autotransformer.

INSTALLATION, CARE, AND OPERATION

122. The successful operation of transformers (Allis-Chalmers Manufacturing Co.) is dependent upon proper installation and operation as much as upon proper design and manufacture. Although a transformer requires less care than almost any other type of electrical apparatus, neglect of certain fundamental requirements may lead to serious trouble, if not loss of the transformer.

123. The following sections (124 to 143) give the requirements of the National Electrical Code for the installation of transformers. These rules have been taken directly from the Code with only some slight rewording and change of section numbers. Where additional material has been added, it is indicated by being printed in italics.

124. Application. —These rules apply to the installation of all transformers, except as follows:

a. Hazardous Locations.—Transformers in hazardous locations shall comply with these provisions except as modified by additional requirements for such locations (*refer to Div.* 9).

b. Current transformers used for metering and protective relays.

c. Dry-type transformers which constitute a component part of other apparatus and which conform to the requirements for such apparatus.

d. Transformers for use with X ray and high frequency.

e. Signaling transformers used with Class 2 remote-control, low-energy power and signal circuits.

f. Transformers for sign and outline lighting, which shall conform to the provisions given in Sec. **316** of Div. 9.

g. Transformers for electric discharge lighting, which shall conform to the special provisions of the Code for such transformers.

125. Location.—They shall be located and arranged to minimize possible life and fire hazards. The location of transformer vaults as affected by ventilating requirements is covered elsewhere.

126. Overcurrent Protection.—Overcurrent protection shall conform to the following. As used in this section, the word "transformer" means a transformer or a bank of transformers operating as a unit.

a. Primary Side.—Each transformer shall be protected by an overcurrent device in the primary connection, rated or set at not more than 250 per cent of the rated primary current of the transformer, except that an individual overcurrent device is not required if the primary circuit overcurrent device provides the protection specified in this paragraph, and except as provided in paragraph *b* of this section.

b. Primary and Secondary Side.—A transformer having an overcurrent device in the secondary connection, rated or set at not more than 250 per cent of the rated secondary current of the transformer, or a transformer equipped with a coordinated thermal overload protection by the manufacturer, is not required to have an individual overcurrent device in the primary connection, provided that the primary feeder overcurrent device is rated or set to open at a current value not more than six times the rated current of the transformers for transformers having not more than 6 per cent impedance, and not more than four times rated current of the transformer for transformers having more than 6 but not more than 10 per cent impedance.

c. Potential (Voltage) Transformers.—Potential transformers should have primary fuses. The fuse rating should not exceed 10 amp. for circuits of 600 volts or less, and 3 amp. for circuits of more than 600 volts. A resistor should be connected in series with high-tension fuses if necessary to limit the possible short-circuit current to a value within the interrupting capacity of the fuse.

127. Secondary Ties.—As used in this section, the word "transformer" means a transformer or a bank of transformers operating as a unit. A secondary tie is a circuit operating at 600 volts or less between phases which connects two power sources or power-supply points, such as the secondaries of two transformers. The tie may consist of one or more conductors per phase.

a. Tie Circuits.—Tie circuits shall be provided at each end with overcurrent protection *according to the current-carrying capacity of the conductors*, except under the conditions described in subparagraphs 1 and 2 of this section, in which cases, the overcurrent protection may be in accordance with subparagraph 3 of this section.

1. Loads at Transformer Supply Points Only.—If all loads are connected at the transformer supply points at each end of the tie, and overcurrent protection is not provided, the rated current-carrying capacity of the tie shall be not less than 67 per cent of the rated secondary current of the largest transformer connected to the secondary tie system.

2. Loads Connected between Transformer Supply Points.—If a load is connected to the tie at any point between transformer supply points, and overcurrent protection is not provided, the rated current-carrying capac-

ity of the tie shall be not less than 100 per cent of the rated secondary current of the largest transformer connected to the secondary tie system, except as otherwise provided in subparagraph 4.

3. Tie-circuit Protection.—Under the conditions described in subparagraphs 1 and 2 of this section, both ends of each tie conductor shall be equipped with a protective device which will open at a predetermined temperature of the tie conductor under short-circuit conditions. This protection shall consist of one of the following: (1) a fusible-link cable-connected terminal, commonly known as a limiter, each being of a size corresponding with that of the conductor and of approved construction and characteristics, according to the operating voltage and the type of insulation on the tie conductors, or (2) automatic circuit breakers actuated by devices having comparable current-time characteristics.

4. Interconnection of Phase Conductors between Transformer Supply Points.—If the tie consists of more than one conductor per phase, the conductors of each phase shall be interconnected in order to establish a load supply point, and the protection specified in subparagraph 3 shall be provided in each tie conductor at this point, except as follows:

Loads may be connected to the individual conductors of a multiple-conductor tie without interconnecting the conductors of each phase and without the protection specified in subparagraph 3 at load connection points, provided: the tie conductors of each phase have a combined capacity not less than 133 per cent of the rated secondary current of the largest transformer connected to the secondary tie system; the total load of such taps does not exceed the rated secondary current of the largest transformer; the loads are equally divided on each phase and on the individual conductors of each phase as far as practicable.

5. Tie-circuit Control.—If the operating voltage exceeds 150 volts to ground, secondary ties provided with limiters shall have a switch at each end which when open will de-energize the associated tie conductors and limiters. The current rating of the switch shall be not less than the rated current of the conductors connected to the switch. It shall be capable of opening its rated current, and it shall be constructed so that it will not open under the magnetic forces resulting from short-circuit current.

b. Overcurrent Protection for Secondary Connections.—When secondary ties are used an overcurrent device rated or set at not more than 250 per cent of the rated secondary current of the transformers shall be provided in the secondary connections of each transformer, and in addition an automatic circuit breaker actuated by a reverse-current relay set to open the circuit at not more than the rated secondary current of the transformer shall be provided in the secondary connection of each transformer.

128. Parallel Operation.—Transformers may be operated in parallel and protected as a unit if their electrical characteristics are such that they will divide the load in proportion to their rating.

129. Guarding.—Transformers shall be guarded as follows:

a. Mechanical Protection.—Appropriate provisions shall be made to minimize the possibility of damage to transformers from external causes if the transformers are located where they are exposed to mechanical injury.

b. Exposed Live Parts.—The transformer installation shall conform with the Code provisions for "Guarding of Live Parts."

c. Voltage Warning.—The operating voltage of exposed live parts of transformer installations shall be indicated by signs or visible markings on the equipment or structures.

130. Grounding.—Exposed non-current-carrying metal parts of transformer installations including fences shall be grounded under the conditions and in the manner prescribed by the Code for electrical equipment and other exposed metal parts.

131. Name Plate.—Each transformer shall be provided with a name plate giving the name of the manufacturer; rated kilovolt-amperes, frequency, primary and secondary voltage; and the amount and kind of insulating liquid, if any, if the transformer rating exceeds 25 kva. If Class B insulation as defined in American Standard for Transformers C 57.1 is used in the construction of dry-type transformers of more than 100 kva., the name plate shall so indicate.

Specific Provisions Applicable to Different Types of Transformers

132. Dry-type Transformers Installed Indoors.—Transformers rated 100 kva. or less shall have a separation of at least 12 in. from combustible material unless separated therefrom by a fire-resistant heat-insulating barrier, or unless of a rating not exceeding 600 volts and completely enclosed except for ventilating openings.

Transformers of more than 100-kva. rating shall be installed in a transformer room of fire-resistant construction unless they are constructed with Class B insulation, as defined in American Standard for Transformers C 57.1, and are separated from combustible material not less than 6 ft. horizontally and 12 ft. vertically or are separated therefrom by a fire-resistant heat-insulating barrier.

Transformers rated more than 15,000 volts shall be installed in a vault.

133. Askarel-insulated Transformers Installed Indoors.—Askarel-insulated transformers rated in excess of 25 kva. shall be furnished with a pressure-relief vent. If installed in a poorly ventilated place, they shall be furnished with a means for absorbing any gases generated by arcing inside the case; or the pressure-relief vent shall be connected to a chimney or flue which will carry such gases outside the building. Askarel-insulated transformers rated more than 15,000 volts shall be installed in a vault.

134. Oil-insulated Transformers Installed Indoors.—Oil-insulated transformers shall be installed in a vault constructed as specified in this article except as follows:

a. Not over 100-kva. Total Capacity.—The provisions for transformer vaults specified in this article apply except that the vault may be constructed of reinforced concrete not less than 4 in. thick.

b. Not over 600 Volts.—A vault is not required, provided suitable arrangements are made where necessary to prevent a transformer oil fire from igniting other materials and the total transformer capacity in one location does not exceed 10 kva. in a section of the building classified as combustible, or 75 kva. in a section classified as fire-resistant.

c. Electric furnace transformers of a total rating not exceeding 75 kva. may be installed without a vault in a building or room of fire-resistant construction if arrangements necessary to prevent a transformer oil fire from spreading to other combustible material are provided.

d. Detached Buildings.—Transformers may be installed in a building that does not conform with the Code provisions for transformer vaults provided that neither the building nor its contents presents a fire hazard to any other building or property and that the building is used only in supplying electric service and is accessible only to qualified persons.

135. Oil-insulated Transformers Installed Outdoors.—Combustible material, combustible buildings and parts of buildings, fire escapes, door and window openings shall be safeguarded from fires originating in oil-insulated transformers installed on, attached to, or adjacent to a building or combustible material. Space separations, fire-resistant barriers, and enclosures which confine the oil of a ruptured transformer are recognized safeguards. One or more of these safeguards must be used as required by the authority enforcing the Code, when the transformer installation presents a fire hazard. Oil enclosures may consist of fire-resistant dikes, curbed areas or basins, or trenches filled with coarse crushed stone. Oil enclosures shall be provided with trapped drains where the exposure and quantity of oil involved are such that removal of oil is important.

Provisions for Transformer Vaults

136. Location.—Whenever practicable, vaults shall be located where they can be ventilated to the outside air without using flues or ducts.

137. Walls, Roof, and Floor.—The walls and roofs of vaults shall consist of reinforced concrete not less than 6 in. thick, masonry or brick not less than 8 in. thick, 12-in. load-bearing hollow tile, or 12-in. load-bearing hollow concrete building units. The inside wall and roof surface of vaults constructed of hollow tile or hollow concrete building units shall have a coating of cement or gypsum plaster not less than ¾ in. thick. The vault shall have a concrete floor at least 4 in. thick. The floor or walls of the building may be used for one or more parts of the vault if they are approved as being equivalent to the foregoing specifications.

138. Doorways.—Any doorway leading from the vault into the building shall be protected as follows:

a. Type of Door.—Each doorway shall be provided with a tight-fitting door of a type approved for openings in Class A situations as defined in National Fire Codes, Vol. 111, NBFU pamphlet No. 80. The authority enforcing this Code may require such a door on each side of the wall if conditions warrant.

b. Sills.—A door sill or curb of sufficient height to confine within the vault the oil from the largest transformer shall be provided, and in no case shall the height be less than 4 in.

c. Locks.—Entrance doors shall be equipped with locks, and doors shall be kept locked, access being allowed only to qualified persons. Locks and latches shall be so arranged that the door may be readily and quickly opened from the inside.

139. Ventilation.—The ventilation shall be adequate to prevent a transformer temperature in excess of the values prescribed in American Standard for Transformers C 57.1.

140. Ventilation Openings.—Openings for ventilation shall be provided in accordance with the following:

a. Location.—Ventilation openings shall be located as far away as possible from doors, windows, fire escapes, and combustible material.

b. Arrangement.—Vaults ventilated by natural circulation of air may have roughly half of the total area of openings required for ventilation in one or more openings near the floor and the remainder in one or more openings in the roof or in the side walls near the roof; or all the area required for ventilation may be provided in one or more openings in or near the roof.

c. Size.—In vaults ventilated to an outdoor area without using ducts or flues, the combined net area of all ventilating openings after deducting the area occupied by screens, gratings, or louvers, shall be not less than 3 sq. in. per kva of transformer capacity in service except that the net area shall be not less than 1 sq. ft. for any capacity under 50 kva.

d. Covering.—Ventilation openings shall be covered with durable gratings, screens, or louvers, according to the treatment required in order to avoid unsafe conditions.

e. Dampers.—If automatic dampers are used in the ventilation openings of vaults containing oil-insulated transformers, the actuating device should be made to function at a temperature resulting from fire and not at a temperature which might prevail as a result of an overheated transformer or bank of transformers. Care should be taken to avoid unintentional closing of automatic dampers.

f. Ducts.—Ventilating ducts shall be constructed of fire-resistant material.

141. Drainage.—If practicable, vaults, containing more than 100-kva. transformer capacity shall be provided with a drain which will carry off

any accumulation of oil or water that may collect in the vault. The floor shall be pitched to the drain opening.

142. Water Pipes and Accessories.—Any pipe or duct systems foreign to the electrical installation should not enter or pass through a transformer vault. If the presence of such foreign systems cannot be avoided, appurtenances thereto which require maintenance at regular intervals shall not be located inside the vault. Arrangements shall be made if necessary to avoid possible trouble from condensation, leaks, and breaks in such foreign systems. Piping or other facilities provided for fire protection or for water-cooled transformers are not deemed to be foreign to the electrical installation.

143. Storage in Vaults.—Materials shall not be stored in transformer vaults.

144. The following instructions (Secs. **145** to **167**) for procedure in installing, caring for, and operating transformers have been taken from National Electrical Manufacturers' Association publication 37–46 and from Transformer Installation Book 5019A of the Allis-Chalmers Manufacturing Co. Except as noted the authority is the N.E.M.A. publication.

145. Location.—Accessibility, ventilation, and ease of inspection should be given careful consideration in locating transformers.

Water-cooled transformers depend almost entirely upon the flow of water through the cooling coils for carrying away heat, so that the temperature of the surrounding air has little effect upon that of the transformers. For this reason air circulation is of minor importance, and water-cooled transformers may be located in any convenient place without regard to ventilation.

146. Self-cooled transformers depend entirely upon the surrounding air for carrying away their heat. For this reason care must be taken to provide adequate ventilation. For indoor installation the room in which the transformers are placed must be well ventilated so that heated air can escape readily and be replaced by cool air from outside. Inlet openings should be near floor level and distributed to be most effective. The outlet or outlets should be as high above the apparatus as construction of building will permit. The number and size of air outlets required will depend on their distance above the transformer, and on the efficiency and load cycle of the apparatus. In general, about 20 sq. ft. of outlet opening or openings should be provided for each 1,000 kva. of transformer capacity. Air inlets should be provided with the same total area as the outlets. If the transformer will be required to operate for considerable periods at continuous full load, the areas of the inlet and outlet openings should be increased to about 60 sq. ft. per 1,000 kva. of transformer capacity.

147. Storage.—When a transformer can be set up immediately in its permanent location and filled with oil, it is advisable to do so, even though it will not be put into service for some time. If this is not convenient it

should be stored in a dry place having no rapid or radical temperature changes, and, if possible, filled with dry transformer oil. The transformer should not be stored or operated in the presence of corrosive gases such as chlorine, etc. If an indoor transformer is stored outdoors, it should be thoroughly covered to keep out rain.

148. Handling.—When lifting a transformer, the lifting cables must be held apart by a spreader to avoid bending the lifting studs or other parts of the structure.

Where a transformer cannot be handled by a crane, it may be skidded or moved on rollers, but care must be taken not to damage the base or tip the transformer over. A transformer should never be lifted or moved by placing jacks or tackle under the drain valve, cooling-coil outlets, radiator connections, or other attachments. When rollers are used under large transformers, skids must be used to distribute the stress over the base.

When working about a transformer, particular care must be taken in handling all tools and other loose articles, since anything metallic dropped among the windings and allowed to remain there may cause a breakdown.

149. Inspection Preliminary to Installation.—Transformers are in first-class operating condition when shipped by the manufacturer, *i.e.*, they have been thoroughly tested for defects and are perfectly dry.

When received, examination should be made before removing from cars, and, if any injury is evident or any indication of rough handling is visible, railroad claim should be filed at once, and the manufacturer should be notified.

Moisture may condense on any metal if the metal is colder than the air, and, if present, it lowers the dielectric strength and may cause a failure of the transformer. Therefore, if transformers or oil drums are brought into a room warmer than they are, they should be allowed to stand before opening until there is no condensation on the outside and they are thoroughly dry.

Before installation, each individual transformer should be thoroughly examined for indications of moisture and inspected for breakage, injury, or displacement of parts during shipment. In addition, all accessible nuts, bolts and studs should be tightened if necessary. Before being placed in service, transformers having a plurality of voltage connections should be carefully checked to ensure that they are connected for operation at the required voltage and on the proper tap.

It is standard practice to ship transformers connected for their maximum voltage.

If transformers are water-cooled, the cooling coils should be tested for leaks at a pressure of 80 to 100 lb. per sq. in. Water, oil, or preferably air may be used in the coil for obtaining the pressure. The coil must be outside the tank, *i.e.*, away from the winding insulation if water is used

for the pressure test. When pressure is obtained, the supply should be disconnected, and after 1 hr. it should be determined whether any fall in pressure is due to a leak in the coil or to a leak in the fittings at the ends of the coil.

150. Transformers Shipped Filled with Oil.—Each transformer shipped filled with oil should be inspected to see whether there is any condition indicating the entrance of moisture during shipment.

If the transformer is received in damaged condition, so that water or other foreign material has had a chance to enter the tank, the transformer should be emptied of oil and treated as though not shipped in oil, and in no case may drying be omitted.

In all cases samples of oil should be taken from the bottom and tested. The dielectric strength of the oil when shipped is at least 22 kv. between 1-in. disks spaced 0.1 in. apart. A new transformer should not be put into service with oil which tests below this value.

151. Transformers Shipped Assembled without Oil.—Each transformer shipped assembled but not filled with oil should be carefully inspected for damage in shipment. A thorough inspection can only be made by removing core and coils from the tank. All dirt should be wiped off and parts examined for breakage or other injuries. All conductors and terminals should be examined to check their proper condition and position. The coil and core clamps should be tightened if necessary.

The tank should be inspected and, if necessary, cleaned.

When a transformer is shipped assembled but not filled with oil, moisture may be absorbed during transportation. For this reason it is good practice to dry out all such transformers, especially transformers above 7,500 volts, before putting them into service.

152. Transformers Shipped Disassembled.—Only very large transformers are shipped in this way, and special instructions covering features incident to this method of shipping are supplied by the manufacturer. These instructions should be carefully followed.

153. Drying Core and Coils.—There are a number of approved methods of drying out transformer core and coils, any one of which will be satisfactory if carefully performed. However, too much stress cannot be laid upon the fact that, if carelessly or improperly performed, great damage may result to the transformer insulation through overheating.

The methods in use may be broadly divided into two classes:

1. Drying with the core and coils in the tank with oil.

2. Drying with the oil removed. The core and coils may or may not be removed from the tank.

154. Drying with Oil in Tank.—Under the first class, the moisture is driven off by sending current through the winding while immersed in oil, with the top of the tank open to the air or with some other arrangement made for adequate ventilation. The current necessary for this class can be secured by the short-circuit method.

This method consists in heating the windings and oil up to a high temperature for a limited time under short circuit with a partial load on the windings, the high oil temperature being obtained by blanketing the tank (or reducing the flow of water for water-cooled transformers).

When a transformer is short-circuited in this manner, only a fraction of the normal voltage should be applied to one winding. In using this method, the load current and maximum top-oil temperature should be in accordance with the tabulation included on the following page.

During the drying run, ventilation additional to that ordinarily provided should be maintained by slightly raising the manhole cover and protecting the opening from the weather. With good ventilation, the moisture, as it is driven off in the form of vapor, will escape to the outside atmosphere, and no condensation of moisture will take place on the underside of the cover or elsewhere, provided these parts are lagged with heat-insulating material to prevent condensation of moisture within.

The following table shows the short-circuit current in percentage of full-load current which may be used for this method of drying transformers, with the corresponding maximum allowable top-oil temperature in degrees centigrade. Less than 5 per cent of normal voltage will usually be required to circulate the current in the windings.

Short-circuit amp. in percentage of full load		Maximum top-oil temperatures, deg. C.
Self-cooled transformers	Water-cooled transformers	
50	50	85
75	60	80
85	75	75

These temperature limits and loads must be strictly adhered to in order to obtain the desired results without danger to the transformers.

It should be noted that the higher allowable temperatures go with the smaller loads, *i.e.*, more blanketing or less water will be required for the smaller loads than for the higher, in order to bring the oil temperature up to the point shown in the table.

When to Discontinue Drying.—Drying should be continued until oil from the top and bottom of the tank tests 22 kv. or higher for seven consecutive tests taken 4 hr. apart with the oil maintained at maximum temperature for the load held and without filtering. The testing of the oil for dielectric strength should be made between parallel disks 1 in. square and spaced $\frac{1}{10}$ in. apart. All ventilating openings should then be closed, and the transformer kept at the same temperature for another

24 hr. without filtering the oil, and as before the oil should be tested at 4-hr. intervals. A decrease in the dielectric strength of the oil indicates that moisture is still passing from the transformer into the oil, and drying should be continued. The temperature of the oil samples when tested should preferably be at room temperature and not in excess of 40°C.

Unless constant or increasing dielectric strength as shown by these tests indicates that drying is completed, the ventilators should be opened, the oil filtered, and the drying process continued.

After the short-circuit run is discontinued, the transformer should be operated for 24 hr. at approximately two-thirds voltage and at the same high temperature, similar tests of oil samples should be made, and the oil filtered if necessary. After satisfactory two-thirds-voltage test, full voltage should be applied for 24 hr., and the same tests repeated. Water-cooled transformers may require some water to hold the top-oil temperature within the 85°C. limit during this test.

155. Drying with Oil Removed.—Typical of the second class, *i.e.*, drying with the oil removed, are the three following methods:

a. By internal heat.

b. By external heat.

c. By internal and external heat.

a. By Internal Heat.—For this method alternating current is required. The transformer should be placed in its tank without the oil and with the cover left off to allow free circulation of air. Either winding can be short-circuited, and sufficient voltage should be impressed across the other winding to circulate enough current through the coils to maintain the temperature at from 75° to 80°C. About one-fifth of normal full rated current is generally sufficient to do this. The impressed voltage necessary to circulate this current varies within wide limits among different transformers but will generally be approximately one-half of 1 per cent to 1½ per cent of normal voltage, at normal frequency.

The end terminals of the winding must be used, not taps, so that current will circulate through the total winding. The amount of current may be controlled by a rheostat in series with the exciting winding. Proper precaution should be taken to protect the operator from dangerous voltage.

This method of drying out is superficial and slow and should be used only with small transformers, and then only when local conditions prohibit the use of one of the other methods.

b. By External Heat.—The transformer should be placed in a box with holes in the top and near the bottom to allow air circulation. The clearance between the sides of the transformer and the box should be small so that most of the heated air will pass up through the ventilating ducts among the coils and not around the sides. The heat should be applied at the bottom of the box. With some types of transformers it is better to distribute the heat evenly around the lower coils.

The best way to obtain the heat is from grid resistors, using either alternating or direct current. The temperature limits of ingoing air are 85 to 90°C. The transformer must be carefully protected against direct radiation from the heaters. Care must also be taken to see that there is no inflammable material near the heaters, and to this end it is advisable to line the wooden box completely with asbestos. Also, when forced air is used, suitable baffles should be placed between heater and inlet to the transformer enclosure.

Instead of placing the heater inside the box containing the transformer, it may be placed outside, the heat being carried into the bottom of the box through a suitable pipe. Where this plan is followed, the heat may be generated by the direct combustion of gas, coal, or wood, provided that none of the products of combustion are allowed to enter the box containing the transformer. Heating by combustion is not advocated except when electric current is not available.

This method, although effective, requires a much longer time than method *c*.

c. By Internal and External Heat.—This is a combination of methods *a* and *b*. The transformer should be placed in a box and external heat applied as in *b*, and current circulated through the windings as in *a*. The current should, of course, be considerably less than when no external heat is applied.

This method is used occasionally where direct current only is available, a certain amount of current being passed through the high-voltage winding only, as the cross-sectional area of the low-voltage conductor is generally too large for it to be heated with an economical amount of direct current. The use of direct current for drying out is not recommended except where alternating current cannot be obtained. When this method of drying is used, the temperature should be measured by the increase-in-resistance method.

Method *c* requires technically skilled supervision.

Time Required for Drying.—There is no definite length of time for drying. One to three weeks will generally be required, depending upon the condition of the transformer, the size, the voltage, and the method of drying used.

Insulation Resistance.—The measurement or determination of insulation resistance is of value in determining the course of drying only when the transformer is without oil. If the initial insulation resistance is measured at ordinary temperatures, it may be high although the insulation is not dry, but as the transformer is heated up it will drop rapidly.

As the drying proceeds at a constant temperature, the insulation resistance will generally increase gradually until toward the end of the drying period, when the increase will become more rapid. Sometimes the resistance will rise and fall through a short range one or more times before reaching a steady high point. This is caused by moisture in the interior

parts of the insulation working its way out through the outer portions which were dried at first.

As the temperature varies, the insulation resistance also varies greatly; therefore the temperature should be kept nearly constant, and the resistance measurements should all be taken at as nearly the same temperature as possible. The insulation resistance in megohms varies inversely with the temperature, and, for a 10°C. change of temperature, the megohms change by a ratio of 2:1. Measurements should be taken every 2 hr. during the drying period.

Resistance Curve.—A curve of the insulation-resistance measurements should be plotted with time as abscissa and resistance as ordinate. By observation, the knee of the curve (*i.e.*, the point where the insulation resistance begins to increase more rapidly) can be determined, and the run should continue until the resistance is constant for 12 hr.

The Allis-Chalmers Manufacturing Co. further recommends that the insulation resistance should be as great or greater than that given by the following formula and that the megohm resistance should be taken with all windings grounded except the one being tested.

Megohms at 85°C. in air or at

$$40°\text{C. in oil} = \frac{\text{kv.} \times 30}{\sqrt{\frac{\text{kva.}}{\text{cycles}}}}$$

where kv. = kilovolts of winding involved; and kva. = kilovolt-amperes of transformer per phase.

The megohms vary inversely with the temperature, and for a 10°C. change of temperature the megohms change in ratio of 2:1. For example,

Megohms at 85°C. = 300
Megohms at 75°C. = 600
Megohms at 65°C. = 1,200
Megohms at 55°C. = 2,400

156. Precautions to Be Observed in Drying without Oil.—As the drying temperature approaches the point where fibrous materials deteriorate, great care must be taken to see that there are no points where the temperature exceeds 85°C. Several thermometers should be used, and they should be placed well in among the coils near the top and screened from air currents. Ventilating ducts offer particularly good places in which to place some of the thermometers. As the temperature rises rapidly at first, the thermometers must be read at intervals of about ½ hr. In order to keep the transformer at a constant temperature for insulation-resistance measurements, one thermometer should be placed where it can be read without removing it or changing its position. The other thermometers should be shifted about until the hottest points are found and should remain at these points throughout the drying period. Wher-

ever possible, the temperature should be checked by the increase-in-resistance method.

157. Caution in Drying Out.—It is well to have a chemical fire extinguisher or a supply of sand at hand for use in case of necessity.

It is not safe to attempt the drying out of transformers without giving them constant attention.

158. Sampling and Testing of Oil.—The sample container should be a large-mouthed glass bottle. All bottles should be cleaned and dried with gasoline before being used. A cork stopper should be used.

The sample for dielectric tests should be at least 16 oz.; if other tests are to be made, 1 qt. (32 oz.).

Test samples should be taken only after the oil has settled for some time, varying from 8 hr. for a barrel to several days for a large transformer. Cold oil is much slower in settling and may hardly settle at all. Oil samples from the transformer should be taken from the oil-sampling valve at the bottom of the tank. Oil samples from a barrel should be taken from the bottom of the drum. A brass or glass "thief" can be conveniently used for this purpose. The same method should be used for cleaning the "thief" as is used for cleaning the container.

When drawing samples of oil from the bottom of the transformer or large tank, sufficient oil must first be drawn off to make sure that the sample will be comprised of oil from the bottom of the container and not from the oil stored in the sampling pipe. A glass receptacle is desirable so that, if water is present, it may be readily observed. If water is found, an investigation of the cause should be made and a remedy applied. If water is not present in sufficient quantity to settle out, the oil may still contain considerable moisture in a suspended state. It should, therefore, be tested for dielectric strength.

For testing oil for dielectric strength, some standard device for oil testing should be used. The standard oil-testing spark gap has disk terminals 1 in. in diameter spaced 0.1 in. apart. The testing cup should be cleaned thoroughly, to remove any particles of cotton fiber, and rinsed out with a portion of the oil to be tested.

The spark-gap receptacle should be filled with oil, both oil and spark gap being at room temperature or approximately 25°C. After filling the receptacle, allow ½ to 1 min. for air bubbles to escape before applying voltage.

The rate of increase in voltage should be about 3,000 volts per sec. Five breakdowns should be made on each filling, and then the receptacle emptied and refilled with fresh oil from the original sample. The average voltage of 15 tests (five tests on each of three fillings) is usually taken as the dielectric strength of the oil. It is recommended that the test be continued until the mean of the averages of at least three fillings is consistent.

The dielectric strength of oil when shipped is at least 22 kv. tested in

the standard gap. If the dielectric strength of the oil in a transformer in service tests at less than 17,500 volts, it should be filtered. New oil of less than the standard dielectric strength should not be put in a transformer.

159. Drying Oil and Filling Transformer.—In removing moisture from transformer oil, it is preferable to filter from one tank and discharge into another, although if necessary it may be drawn from the bottom of a tank and discharged at the top. When there is much water in the oil, it should be allowed to settle, and then be drawn off and treated separately.

Before the transformer is filled with oil, all accessories, such as valves, gages, thermometers, plugs, etc., must be fitted to the transformer and made oiltight. The threads should be filled in accordance with instructions from the manufacturer before putting them in place. The transformers must be thoroughly cleaned.

Metal hose must be used for filling instead of rubber hose, because oil dissolves the sulphur found in rubber and may cause trouble if the sulphur attacks the copper.

The oil used should be clean, dry oil of the grade recommended by the manufacturer.

The use of a filter press is recommended, and if one is not available some precaution should be taken to strain the oil before putting it in the transformer.

After filling the transformer, the oil should be allowed to settle at least 12 hr., and then samples taken from the bottom should again be tested before voltage is applied to the transformer.

It is very important that the surfaces of the oil when cold (25°C.) be at the oil level indicated by the mark on the oil gage. When the transformer is not in service, the oil level must never be allowed to fall to a point where it does not show in the gage. When it is necessary to replenish the oil, care must be taken to see that no moisture finds its way into the tank. As the oil heats up with the transformer under load, it will expand and rise to a higher level.

160. Putting into Service.—When the voltage is first applied to the transformer it should, if possible, be brought up slowly to its full value so that any wrong connection or other trouble may be discovered before damage results. After full voltage has been applied successfully, the transformer should preferably be operated in that way for a short period without load. It should be kept under observation during this time and also during the first few hours that it delivers load. After 4 or 5 days' service it is advisable to test the oil again for moisture.

If the transformer is water cooled the main water valve should be opened as soon as the oil temperature reaches 45°C. If there are two or more sets of cooling coils in parallel, the valves of all sections should be adjusted for equal rates of flow. This can be estimated by feeling the

weight of the discharge streams from the different sections. It can be determined best, however, by noting the difference in temperature between ingoing and outgoing water from each section. A careful measure should be taken of the total amount of water flowing through all sections, and the total rate of flow should be adjusted to a value not less than that specified.

161. Care.—The idea that a transformer in service needs no attention may lead to serious results. Careful inspection is essential, and the directions given in this section should be followed.

In spite of all precautions, moisture may be absorbed by the transformer if it is of the open type, and during the first few days of operation it is well to inspect the inside of the manhole cover for moisture. If sufficient moisture has condensed to drip from the cover, the transformer should be taken out of service and dried. The oil should be tested and dried if necessary.

Closed-type transformers should have their oil tested at top and bottom after the first few days of operation to make sure that no moisture is being given off from the transformer into the oil.

Samples of oil from all transformers should be drawn and tested at least once every 6 months.

During the first month of service of transformers having a potential of 40,000 volts or over, samples of oil should be drawn each week from the bottom of the tank and tested.

If at any time the oil should test below 17,500 volts, it should be filtered.

Closed-type transformers when properly dried out and installed will need thorough inspection only infrequently, *i.e.*, only when there are specific indications of trouble. Other types of transformers should be taken out of service periodically for a thorough inspection. The inside of the cover and the tank above the oil should be regularly inspected to see that it is clean, dry, and free from moisture and that the thermometer bulb is clean. If an appreciable amount of dirt or sediment is found inside the case, it is best to untank the transformer and remove the oil from the tank. The transformer and the tank should then be cleaned thoroughly and the oil filtered and tested. In cleaning, only dry cloths or waste should be used. Care should be taken to see that all nuts are tight and that all parts are in their proper places. If the transformer is water cooled, the cooling coils should be cleaned thoroughly. The transformer and the oil should be replaced in the tank, and, when the cover is put on, all cracks and openings should be closed tightly.

In the case of water-cooled transformers the rate of flow should be checked from time to time, and, if it is found to have diminished, the cause should be looked for and remedied. The most frequent cause of clogging of cooling coils is the presence of air in the water, resulting in the formation of a scaly oxide.

162. Removing Scale from Cooling Coils.—Scale and sediment can be removed from a cooling coil without removing the coil from the tank. Both inlet and outlet pipes should be disconnected from the water system and temporarily piped to a point a number of feet away from the transformer, where the coil can be filled and emptied safely. Especial care must be taken to prevent any acid, dirt, or water from getting into the transformer.

All the water should be blown or siphoned from the cooling coils, which should then be filled with a solution of hydrochloric (muriatic) acid—specific gravity, 1.10. (Equal parts of commercially pure concentrated hydrochloric acid and water will give this specific gravity.)

It may be found necessary to force this solution into the cooling coils. When this is done one end of the coil should be partially restricted, so that the solution will not be wasted when the coil is full. After the solution has stood in the coil about 1 hr., the coil should be flushed out thoroughly with clean water. If all the scale is not removed the first time, the operation should be repeated until the coil is clean, using new solution each time. The number of times it is necessary to repeat the process will depend on the condition of the coil, though ordinarily one or two fillings will be sufficient.

As the chemical action which takes place may be very violent and may often force acid, sediment, etc., from both ends of the coil, it is well to leave both ends partially open to prevent abnormal pressure.

163. Idle Cooling Coils.—When a water-cooled transformer is idle and exposed to freezing temperatures, the water must be blown out of the cooling coil. In addition to blowing out the water, the cooling coils should be dried by forcing heated air through them. If it is not convenient to do this, the coil should be filled with transformer oil.

164. Stopping Oil Leaks (Allis-Chalmers Manufacturing Co.).—Oil leaks at gasketed joints can often be stopped by tightening the bolts, but if this is not effective new gaskets must be installed. Special cork is available for this purpose. An adhesive such as shellac, bakelite varnish, or other suitable material should be used.

Oil leaks at welds may be stopped by peening, soldering, or welding. Peening is often effective for small stains, and soldering alone or a combination of peening and soldering will usually be effective with larger leaks. For this purpose an excellent hard solder having a melting point of 365°F., known as Iron Fix, can be purchased from The Aluminum Fix Co., Cleveland, Ohio. Special soldering coppers and a special flux are provided along with specific instructions.

Leaks which cannot be stopped by any of these methods must be welded. In welding transformer tanks with the core and coils in place the oil should not be removed.

165. Operation (General).—An artificially cooled transformer should not be run continuously, even at no load, without the cooling medium.

Therefore, it is essential to maintain a proper circulation in the cooling system.

If the water circulation in a water-cooled transformer is stopped for any reason, the load should be immediately reduced as much as possible and close watch kept of the temperature of the transformer. When the oil at the top of the tank reaches 80°C. the transformer must be cut out of service at once. This temperature should be recognized as an absolute limit and must not be exceeded. It should be held only during an emergency period of short duration.

Nearly all cooling water will in time cause scale or sediment to form in the cooling coil. The time required to clog up the cooling coils depends on the nature and amount of foreign matter in the water. The clogging materially decreases the efficiency of the coil and is indicated by a high oil temperature and a decreased flow of water, load condition and water pressure remaining the same.

166. Temperature.—Thermometers should be read daily or more often. If, at rated load or less, the oil temperature reaches 80°C. for an oil-immersed, self-cooled transformer or an oil-immersed, forced-air-cooled transformer, or 65°C. for an oil-immersed, water-cooled transformer, it is advisable to check operating conditions.

Oil-immersed, self-cooled transformers or oil-immersed, forced-air-cooled transformers should not be operated for long periods of time at oil temperatures in excess of 80°C. on account of increased rate of deterioration of the insulations. The oil temperature in these transformers should not be allowed to exceed 90°C. even for short periods of time.

If the oil temperature in oil-immersed, water-cooled transformers should exceed 65°C. at rated load or less, either the cooling coils need cleaning, an insufficient amount of cooling water is being used, or the temperature of the cooling water is higher than 25°C. The oil temperature in oil-immersed, water-cooled transformers should not be allowed to exceed 75°C. even for short periods of time. A lower oil temperature is recommended for oil-immersed, water-cooled transformers on account of the greater difference between the temperatures of the windings and of the oil than in oil-immersed, self-cooled transformers.

Regardless of oil temperatures as indicated by thermometers, transformers should not be operated continuously at overloads in excess of 1 per cent for each degree that the ambient is below 30°C. for air and 25°C. for water. In no case should the overload exceed 30 per cent for self-cooled transformers and 25 per cent for water-cooled transformers unless stipulated by the specification or contract. During overloads the transformer should be watched with special care.

Moisture may get into an open-type transformer owing to the fact that as oil is heated and cooled it expands and contracts, causing air to be expelled from and drawn into the transformer. If the air which enters the transformer is at the same time cooled by contact with the cover to below its dew point, moisture will condense.

It is therefore good practice to operate transformers at several degrees above air temperatures at all times. This will largely prevent condensation.

167. Recommendations Relative to Pole-mounted Transformers. Pole Mounting.—Convenient lugs or eyebolts are provided on the side of the case to which the rope lifting the transformer may be attached. It will be found convenient to fasten the hanger irons to the case before the transformer is raised to the crossarm. The transformer can then be raised up to and slightly above the crossarm, and the hooks on the hanger irons can then be made to engage the crossarm by lowering the transformer.

Pole-mounted transformers may be filled with oil either before or after mounting, as desired. It is sometimes necessary to add oil a short time after the transformer has been installed, owing to the fact that the insulation will absorb a certain amount of oil. It may be found necessary to replenish the oil from time to time during actual operation in order that the normal oil level be kept constant. When the transformer oil is replenished, care should be taken that no moisture finds its way inside the case.

Replacing the Cover.—Great care should be exercised in putting on the cover. If the gasket is not properly in place or the cover not securely bolted to the case, moisture in the form of snow or rain may be driven into the transformer tank.

It is very important that the surface of the oil when cold (25°C.) be at the oil level indicated on the inside of the tank or on the oil gage.

The following practice is recommended for the care of pole-mounted distribution transformers in service:

1. The oil level should be inspected once every year and enough oil added to bring the level up to the mark inside the tank or on the oil gage.
2. Periodically the condition of the oil should be inspected, and if necessary the oil should be removed and replaced with good clean oil.
3. A periodic check of the load should be made to make sure a transformer is not being overloaded.

168. Care and operation of transformers immersed in noninflammable, nonexplosive liquids is, in general, the same as for those which are oil immersed. The liquid may be dehydrated and filtered by means of special equipment designed for the purpose. Regular oil-filtering equipment cannot be used. The same great care with respect to moisture must be taken with these transformers as the regular types. The transformer cover should not be taken off in a manhole.

Precaution should be taken in handling the liquid as it has an irritating effect upon the skin; more so to some persons than others. Especially the eyes, nose, and lips are affected when coming in contact with the liquid, and safety precautions must be observed when handling it.

When handling the liquid or working on a transformer filled with the liquid, an application of castor oil is recommended for the eyes, and castor

oil or cold cream for the nose and lips. In case the liquid comes in contact with the skin, the part should be thoroughly washed and cleaned.

A person should be careful about looking down into the transformer case, as the liquid gives off a gas at 80°C. which causes irritation to eyelids, nostrils, and lips. When working around one of these transformers the hands should be coated with grease and the eyes, nose, and lips protected as advised above.

POLE AND PLATFORM MOUNTING OF TRANSFORMERS

169. Mounting Distributing Transformers.—Units of the smaller capacities are supported either directly on the poles or on crossarms in accordance with instructions furnished by their manufacturers. Gear and Williams recommend that, for transformers of capacities larger than 20 kw., double crossarms should be used at the top, as the top arms carry

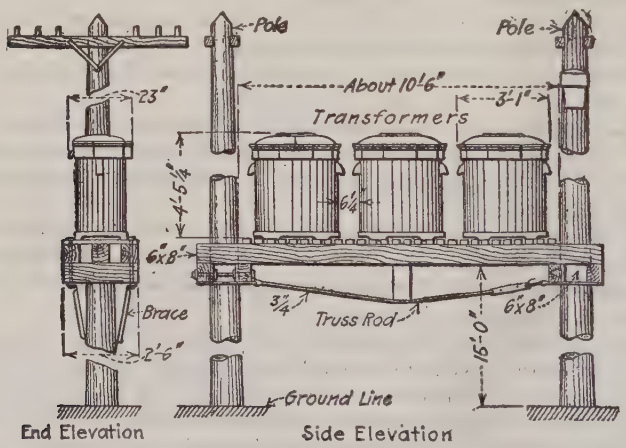


FIG. 75.—Platform for large transformers.

most of the weight. "Where the installation consists of three 15-kw. or larger transformers it is advisable to use a larger-sized crossarm than the standard. An arm having a cross section of 4 by 5½ in. has been found ample for installations aggregating 90 to 100 kw."

"Where a large amount of power is needed which requires a number of 50-kw. units which cannot be conveniently installed inside the building, they can be safely and conveniently installed on a platform between two or more poles as shown in Fig. 75. The use of units larger than 50 kw. is usually not advisable as they are so heavy as to be inconvenient to handle, and replacing them in case of a burnout is a considerable task. A platform for supporting three 50-kw. units can be

built by bolting in gains, between two poles, 2–3 in. × 10-in. planks and nailing to them a floor of 2-in. plank."

170. Methods of Crossarm and Platform Mounting of Transformers.—The methods of mounting transformers described and illustrated in the following paragraphs were taken from a "Report of the Committee on Overhead Line Construction" of the Pennsylvania Electric Association. The practices outlined were those followed by the Allegheny County

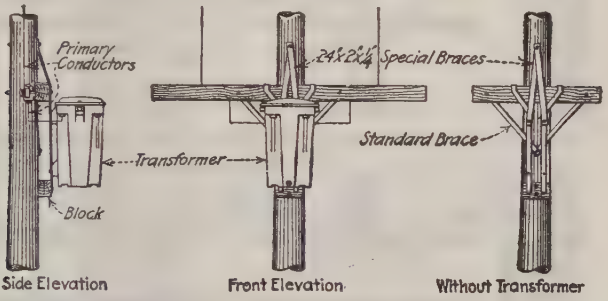


FIG. 76.—Method of supporting a 5- to 10-kw. transformer.

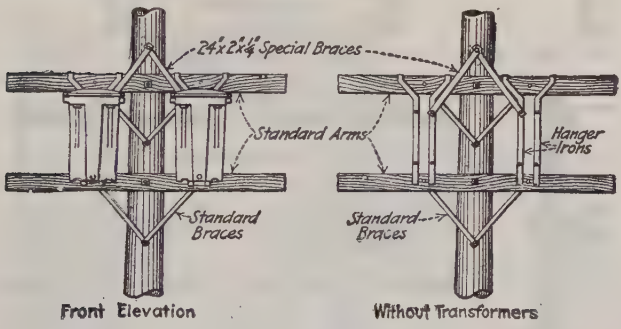


FIG. 77.—Method of supporting two 5-kva. or two 10-kva. transformers.

Light Co. The methods provide ample clearances for linemen climbing the poles and assure that the wiring will remain in place and not give trouble from short circuits. Platforms are recommended for supporting the larger transformers because of the accessibility for repairs or replacements that they provide.

171. Crossarm Method of Mounting Single Transformers of from 1- to 4-kva. Capacity.—The transformer should be supported by the iron hangers furnished by the manufacturer and hung at the central point on the crossarm and not out on the arm away from the pole. At the bottom of the hanger a section of an arm, not longer than the diameter of the pole, should be fastened to the pole with two lag bolts. The trans-

former can be hung on the bottom arm, if one is in place and supports lines, provided this arm is in the second gain or a lower one. The primary mains feeding the transformer should be on an upper arm.

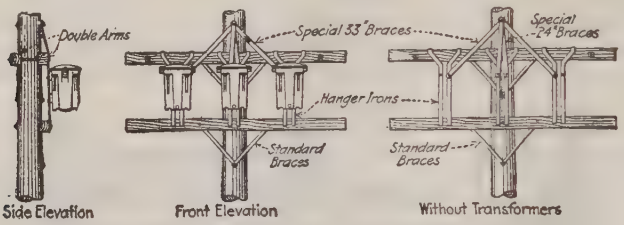


FIG. 78.—Method of supporting three 5-kva. transformers.

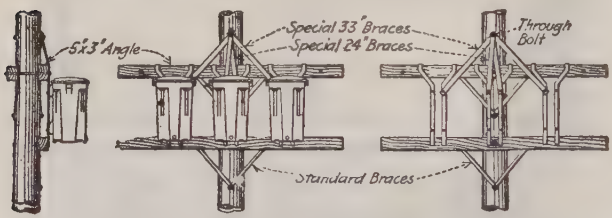


FIG. 79.—Method of supporting three 10-kva. transformers.

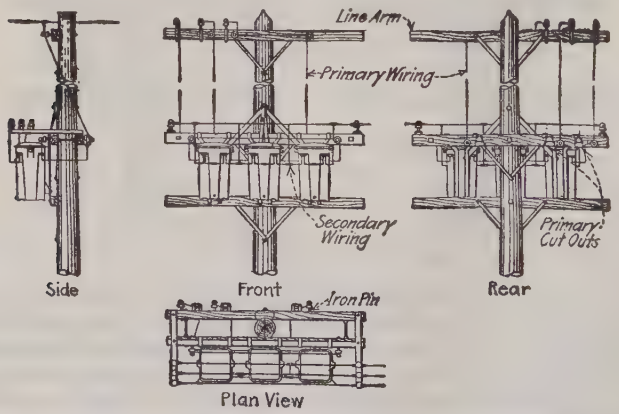


FIG. 80.—Wiring for three 5-kva. or for three 10-kva. transformers.

In installations where the transformers are more than 4 ft. below the arm supporting the primary mains, it is advisable to mount Western Union pins horizontally in the line arms. On these pins the primary wires can be tied to maintain them rigid. Iron pins should also be mounted

in the transformer arm to take the stress imposed on the primary conductors by the fuse terminal screws.

172. Method of Mounting Transformers of from 5- to 30-kva. Capacity (Fig. 76).—The same rules should be followed as outlined in the

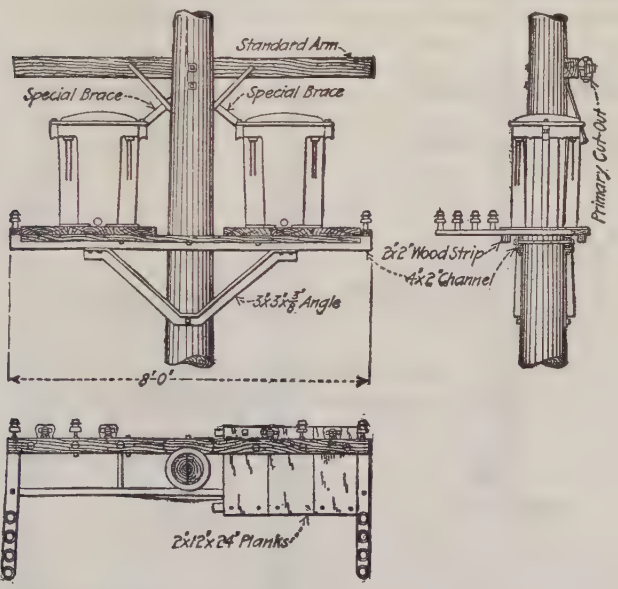


FIG. 81.—Single-pole platform for two 20-kva., two 30-kva., or one 50-kva transformer.

preceding paragraph with the following additions: The transformers, on account of their increased weight and dimensions, should not be hung on a line arm. A specially placed arm should be used underneath existing arms and other apparatus. In addition to using the regular hangers which accompany transformers, a pair of iron braces $24 \times 2 \times \frac{1}{4}$ in. should be placed between the transformer lugs and the hanger with the hanger bolts passing through one of the holes in the braces. These braces are to be run in an upward direction and fastened to the pole with a standard through bolt (see Fig. 76). If the arm weakens or entirely rots away, these two braces are of sufficient strength to support the transformer and permit crossarm replacement.

173. Method of Mounting Two 5-kva. or Two 10-kva. Transformers (Fig. 77).—Construction similar to that above described should be used except that a standard arm should be placed at the bottom on which the hanger irons can rest. Also only one special brace ($24 \times 2 \times \frac{1}{4}$ in.)

per transformer should be placed between the lug and hanger iron next to the pole.

174. Method of Mounting Three 5-kva. Transformers (Fig. 78).—The construction should be similar to that outlined in the preceding paragraphs, except that the special braces supporting the outside transformers are 33 in. between centers of holes. It is also advisable to place

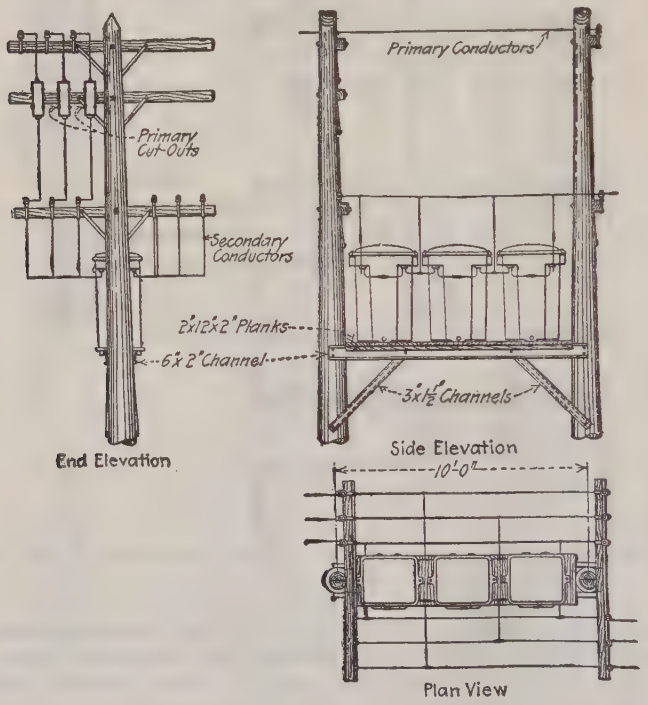


FIG. 82.—Double-pole platform for three 20-kva., two 50-kva., or three 50-kva. transformers.

an additional crossarm on the rear side of the pole. This arm braces the front arm and provides a place where fuse blocks can be mounted.

175. Method of Mounting Three 10-kva. Transformers (Figs. 79 and 80).—The construction is similar to that for three 5-kva. transformers with the following addition: The top arm supporting the transformers should be reinforced with a piece of angle iron 5 × 3 in. × the length of crossarm, which should be placed with the 3-in. leg on the top of the arm.

176. Method of Mounting Two 20-kva., Two 30-kva., or One 50-kva. Transformer (Fig. 81).—For transformers of these capacities a single-

pole platform is recommended. The beams for the platform should be 4 in. × 6 lb. channel iron 8 ft. long. The braces used are a single piece of angle iron 3 × 3 × ⅜ in. bent in a V shape. Pine or oak planks 2 × 12 × 24 in. are to be laid across the channel irons for the transformers to rest upon. The wooden platform is to be held together by a 2 × 2 in. strip of wood running on the outside of the channel iron, to which the planks are secured by 4-in. wood screws or 20-penny nails.

177. Method of Mounting Three 20-kva., Three 30-kva., Two 50-kva., or One 50-kva. Transformer (Fig. 82).—The poles should be spaced 10 ft. apart on centers. The main channel irons are 6 in. × 10 lb. × 10 ft. 6 in. over all. Braces are of 3 in. × 4 lb. channel.

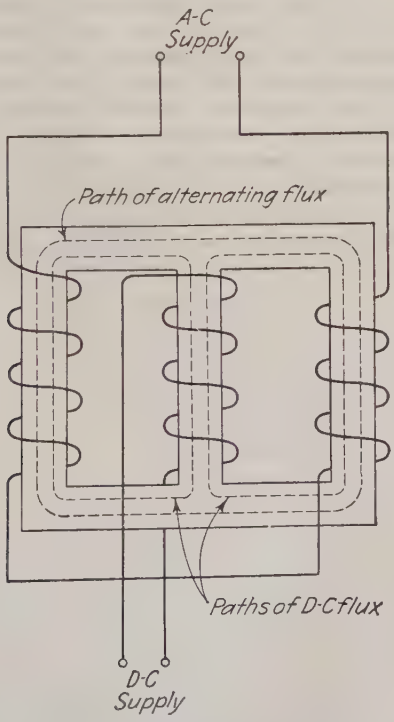


FIG. 83.—Saturable-core reactor.

SATURABLE-CORE REACTOR

178. Saturable-core Reactor.—In many control circuits it is desirable to be able to control the value of the inductive reactance. This can often be accomplished advantageously by means of a device called a saturable-core reactor. A saturable-core reactor consists of a magnetic core

associated with d-c and a-c windings. A common form of construction is shown in Fig. 83. When there is no current in the d-c winding, the inductive reactance of the a-c winding will be high, since there will be a high rate of change of flux with current. If sufficient direct current is passed through the d-c winding to saturate the magnetic core, then the changing current in the a-c winding will produce only very small changes in the flux of the core, and the inductive reactance of the a-c winding will be very small. By adjusting the current of the d-c winding, the inductive reactance of the a-c winding may be varied smoothly from practically zero to its maximum value. It might appear that a saturable-core reactor could be constructed with one a-c and one d-c winding on a common core. This simple construction would not be satisfactory, since the variations of the flux produced by the alternating flux would induce large voltages of changing magnitude in the d-c winding. To be satisfactory, the reactor must be so constructed that the flux linked with the d-c winding is not affected by the alternating current in the a-c winding. This can be accomplished by the construction of Fig. 83. The currents in the two a-c coils tend to produce flux in opposite directions through the central core on which the d-c winding is wound. Therefore, the currents in the a-c windings neutralize each other with respect to the production of flux linking with the d-c winding. Refer to Sec. **29** of Div. 6 for an application of a saturable-core reactor in a control circuit.

DIVISION 6

ELECTRON TUBES AND CIRCUITS

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FUNDAMENTALS OF ELECTRONICS

1. Electronics, as defined by the American Institute of Electrical Engineers, is that branch of science and technology which relates to the conduction of electricity through gases or in vacuum.

The reader should study, in Div. 1, Secs. **25** to **30** and Sec. **39** before proceeding with this division on electronics.

Electricity exists in two forms called positive and negative electricity, respectively. Positive electricity is that form of electricity which is associated with the nuclei of the atoms of all matter, and negative electricity is that form of electricity which is associated with the very minute particles of matter called electrons. In its normal state an atom of matter contains just as much positive electricity as negative electricity. Except under very unusual conditions, no electricity can be removed from the positive nucleus of an atom; and, therefore, no positive electricity can be transferred from one atom to another or from one material to another. Electrons, however, can be removed or added to an atom and, after having been separated from an atom, can be transferred from one material or medium to another.

An atom, molecule, or piece of material that possesses more electricity of one kind than the other is said to be electrically charged. It is positively charged if some of the normal electrons have been removed from it, so that it contains more positive electricity than negative electricity. It is negatively charged if electrons have been added to it, so that it contains more negative electricity than positive electricity.

In matter in its solid form, the electrons are not absolutely bound to the nuclei of the atoms. Some electrons will break away from their atoms, move about in heterogeneous directions in the space between atoms, and eventually combine with other atoms. These electrons, which are relatively free of atoms, are called free electrons. It is the controlled motion of these free electrons which constitutes electric current in solid materials. Some materials possess a large number of free electrons, and current is therefore relatively easily produced through these materials. These materials are called conductors. Other materials possess only a very limited number of free electrons, and current is therefore very hard to produce through them. These materials are called insulating materials.

In any piece of solid material there are internal forces that tend to hold the free electrons inside the material. It is relatively easy to overcome these restraining forces at the boundary between two solid

conducting materials. However, it is relatively hard to produce the emission of electrons from a conducting body through the boundary of the body into an insulating solid material, into a gas, or into a highly evacuated space.

Electronic devices (tubes) function principally through the conduction of free electrons through gas or in vacuum. The functioning of these devices, therefore, involves

1. The production of free electrons in an evacuated or gas-filled space (emission).

2. The production of motion of these free electrons through the evacuated or gas-filled space (production of current through the space).

3. The control of the motion of these free electrons through the space, (control of the current through the space).

2. Electron Emission.—The free electrons, which must be maintained inside an electron tube, are produced by emitting electrons from a conducting electrode into the highly evacuated or gas-filled space. The principal methods by which this emission is produced are

1. Thermionic emission.
2. Electric-field emission.
3. Photoelectric emission.
4. Secondary emission.

Thermionic emission is produced by heating a metal to a high enough temperature so that free electrons in the metal will be given sufficient energy to break through the surface of the metal and to be emitted into the space surrounding the metal. Only those metals are satisfactory for use as thermionic emitters which will produce liberal emission of electrons at temperatures well below the melting point of the metal. The principal materials used are tungsten, thoriated tungsten, and oxide-coated tungsten or platinum. The common coatings are oxides of barium and strontium.

Electric-field Emission.—When voltage is impressed between two separated conductors, forces tending to remove electrons will be exerted upon the electrons in the conductor that is connected to the negative terminal of the supply. If the voltage is sufficient, electrons will be emitted from the surface of that conductor into the surrounding space. Solid metallic emitters, similar to those used as thermionic emitters, and pools of mercury are the principal materials used for electric-field emission.

Photoelectric Emission.—When light falls upon an object, some of the radiant energy of the light is imparted to the body. In some substances sufficient energy is imparted by light to electrons in the substance so that electrons are emitted into the surrounding space. The light-sensitive substance, employed for photoelectric emitters, depends upon the particular wave lengths of light to which it is desired to have the emitter respond. Cesium oxide, potassium, and sodium are common light-sensitive materials employed for photoelectric emission.

Secondary Emission.—The energy required to release electrons from a conducting surface may be provided by bombarding the surface with electrons or ions (electrically charged particles of matter) of sufficiently high kinetic-energy content. A bombarding electron at high speed may produce the liberation of up to 10 electrons. In a few specialized types of tubes, secondary emission is employed as the primary or contributary cause of emission; but in most cases it is to be avoided, since secondary emission may result in decreasing the useful purpose of the tube or in damage to the electrodes.

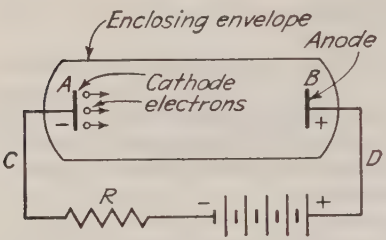


FIG. 1.—Conduction in vacuum.

3. Conduction in Vacuo.—A perfect or complete vacuum is perfectly void space, *i.e.*, space containing absolutely nothing. It is impossible for man to produce a perfect vacuum. Our so-called vacuums are very highly evacuated space, *i.e.*, space that contains only a very minute amount of matter in the gaseous form.

Consider the conditions of Fig. 1, in which two cold electrodes of conducting material A and B are enclosed in a highly evacuated chamber. Since the envelope cannot be completely evacuated and will contain a minute amount of gas, a very, very small number of free electrons will be present inside the chamber. With a moderate voltage of the polarity shown impressed between electodes A and B, a very, very minute current would flow for an infinitesimal lapse of time. This current would consist of the motion to the electrode B of the few free electrons present in the evacuated chamber, and the current would cease as soon as all the free electrons present had been moved to electrode B. No current except this very, very minute initial current could exist unless electrons were emitted into the chamber. If electrode B were caused to be an emitter of electrons, no current would exist through the chamber, since the voltage is of such polarity that it would immediately drive the emitted electrons back into electrode B. However, if electrode A were caused to be an emitter, the voltage would exert a force upon the emitted electrons, moving them through the chamber to electrode B. As long as electrode A continued to give emission, there would be current in the circuit. This current would consist of motion of electrons from the positive terminal of the voltage source, through the source to the negative terminal, through resistor R and conductor C to the negative electrode A, through the boundary of A into the chamber (emission of electrons from electrode A into the chamber), through the space of the evacuated chamber to electrode B, and through conductor D back to the positive terminal of the source. Either electrode A or B may be caused to be an

emitter by thermionic, photoemissive, or electric-field means. To cause either A or B to become an emitter by electric-field means would require a high voltage.

The magnitude of the current through a vacuum will be determined by (1) the rate of emission of electrons, (2) the voltage impressed between electrodes A and B, (3) the distance from electrode A to electrode B, and (4) the shape of the electrodes. As compared with other circuits, the current through a vacuum will be relatively small. In conduction through matter, both positive and negative electricity are present in the material. In conduction through a vacuum, only negative electricity is present in the vacuum. This presence in the space of only negative electricity (called space charge) results in forces that oppose the motion of the negative electrons away from the emitter. It is this opposition of the space charge to motion of electrons away from the emitter which limits the current per unit of impressed voltage to relatively low values. The voltage drop from electrode A to electrode B will increase with increased current because of greater space-charge effect. For a given rate of emission, the current will increase as the impressed voltage is increased until the electrons are moved across the vacuum space as fast as they are emitted. Any further increase in impressed voltage cannot increase the current. However, in the operation of a vacuum-tube circuit, it is impossible to hold the emission constant. As the voltage from A to B is increased, the emission is increased very slightly.

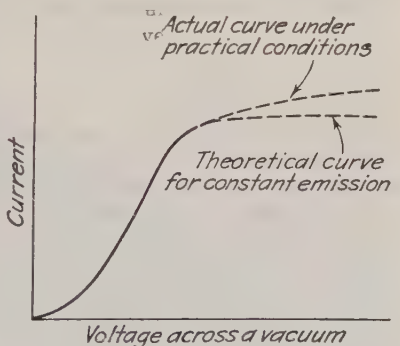


Fig. 2.—Typical current-voltage characteristics for conduction in vacuum.

A typical current-voltage characteristic of vacuum conduction is shown in Fig. 2. The shape of the lower portion of the curve will depend upon the shape and location of the electrodes.

4. Electronic Direction of Current.—In the discussion of the current in Sec. **3**, it will be noted that the motion of the electrons constituting the current is opposite to the direction in which current is commonly considered to be. The early experimenters assumed current to consist of the motion of positive electricity, and that assumption is the basis for our present-day common terminology with respect to direction of current. We now know that, in most cases, current actually consists of the motion of negative electricity (electrons). However, since the effects produced by motion of negative electricity in one direction are the same as those produced by the motion of positive electricity in the opposite direction,

no harm is done by considering the current to consist of equivalent motion of positive electricity. The conventional or common direction of current is the direction in which positive electricity would move in order to produce the same effects as those produced by the actual motion of negative electricity in the circuit. The conventional direction of current is always assumed unless otherwise stated. When the actual direction of motion of electrons is considered, it is called the electronic current.

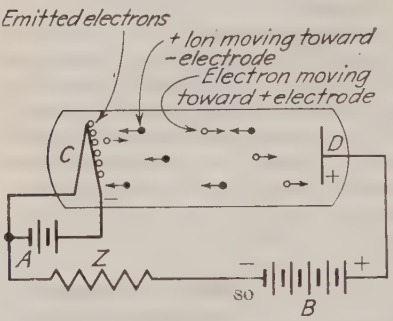


FIG. 3.—Conduction in a low-pressure gas.

5. Conduction in Gases.—Since highly evacuated space is not a perfect vacuum, the enclosure does contain a minute amount of gas. This minute amount of gas, however, is so small that it plays no appreciable part in conduction through the highly evacuated space. If an appreciable amount of gas is present in an enclosure, it will alter the conduction characteristics so that they differ to a marked degree from those present in highly evacuated space. The conduction conditions in gas will depend upon the pressure and the method of emission. The following discussion of gaseous conduction is for relatively low pressures, such as those which are employed in electron tubes.

Consider, first, the conditions of Fig. 3 in which two electrodes *C* and *D* are enclosed in a gas-filled chamber. Electrode *C* is constructed to produce liberal emission when it is heated to the proper temperature by current from the voltage source *A*. Electrode *D* will not produce emission unless an excessive voltage is impressed across the two electrodes. When a small voltage *B* of the polarity shown is impressed across the electrodes, the electrons emitted by *C* will be moved through the gas to the positive electrode *D*. Since the gas of itself will contain some free electrons in addition to those emitted by electrode *C*, the amount of

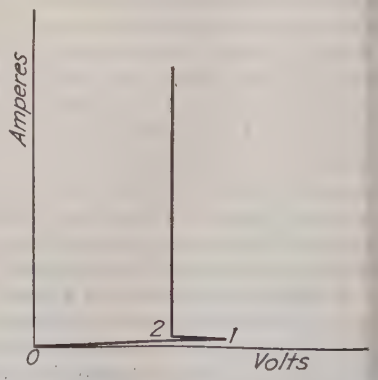


FIG. 4.—Plate current–plate voltage characteristic of a gas-filled tube with liberal emission.

current through the enclosure will be somewhat greater than it was when the chamber was highly evacuated, and the current-voltage characteristic will have a different shape, as shown in Fig. 4 from point 0 to 1. The conventional direction of current will be from electrode D through the gas of the enclosure to electrode C. If electrode C were made of positive polarity with respect to D, the electrons emitted by C would be driven back into the emitting electrode C, and no current would pass through the gas. With D of positive polarity, the electrons in moving through the gas-filled space will be impeded in their motion by collisions with atoms of the gas. Some of the energy imparted to the moving electrons by the source of voltage will be transformed by these collisions into heat energy. As the voltage across electrodes C and D is increased, the electrons will be accelerated more rapidly in their motion toward the positive electrode D and therefore will possess more energy when they collide with an atom of the gas. When the voltage has been raised to a certain value, point 1 in Fig. 4, an electron will possess enough energy on collison with an atom so that an electron will be knocked off from the atom, and the atom will be left with a positive charge. This liberation of electrons and production of positively charged atoms is called ionization of the gas. These liberated electrons and positively charged atoms will provide a liberal number of current carriers throughout the whole enclosure, and the gas will become a good conductor of electricity. This increased conductivity of the gas will allow the current to increase suddenly when point 1 in Fig. 4 is reached, and the voltage required to maintain the conduction will drop to the value corresponding with point 2. The current after condition 2 has been reached will consist of combined motion of negative electrons toward the positive electrode and of positively charged ions toward the negative electrode. Because of the presence of both negative electrons and positively charged ions throughout the space, there will be practically no net space charge inside the enclosure. In conduction in vacuum, the current was limited by space charge, and greater current required greater voltage drop across the electrodes to produce it. After ionization in gaseous conduction, the current will be independent of the voltage for a considerable range, as from point 2 upward in Fig. 4. Throughout this range the voltage drop between the electrodes will be constant regardless of the value of the current. The voltage to produce ionization (the voltage for point 1 in Fig. 4) is a few volts greater than the voltage required to maintain ionization (the voltage for point 2 in Fig. 4). The original production of the ionization is called the breakdown of the gas. With thermionic emission, if the current is allowed to reach too high a value, the bombardment of the emitter by the positively charged atoms will destroy the emitting surface of the emitter. An external impedance z must therefore be inserted in series with the circuit so as to limit the current to a safe value. Gas-filled tubes with thermionic emitters are

operated on the points of the curve from point 2 upward to the safe value of current for the particular tube.

If the lower portion of the gaseous-conduction characteristic for liberal emission conditions is redrawn to an expanded scale, it will appear as shown in Fig. 5. If the emission produced by electrode C is reduced, the conduction characteristic will be as shown in curve 2 of Fig. 5. Reducing the emission will raise the voltage required to break down the gas and will reduce the magnitude of the current for the portion of the conduction characteristic from 0 to 1. The amount of emission produced by photoelectric means is limited, and gas-filled phototubes are operated on the lower portion of the conduction characteristic from 0 to 1.

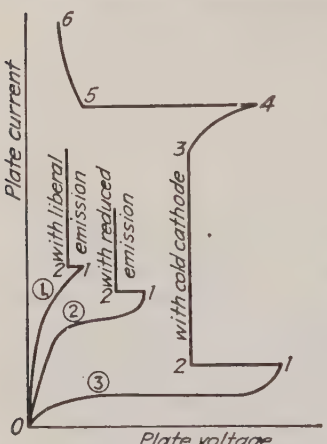


FIG. 5.—Plate current–plate voltage characteristics for gas-filled tubes.

If the two electrodes C and D are operated cold, so that neither electrode is heated by external means, as shown in Fig. 5, no current of any appreciable magnitude will exist through the gas for small values of impressed voltage. Actually a very, very minute current of approximately $\frac{1}{100}$ microampere will pass from electrode D to C. This minute current will be maintained by a minute amount of emission from electrode C. The emission is undoubtedly caused by field emission. This minute current is shown in curve 3 of Fig. 5. If the voltage across C and D is increased above the value for point 1 on curve 3, the gas will be broken down, and emission will be increased. The emission after point 1 is reached will be caused by all four of the methods described in Sec. 2. The same action of ionization and conduction will take place as described for the conditions when electrode C was a thermionic emitter. However, the voltage required to produce breakdown with cold electrodes will be much greater than for hot operation of electrode C. After breakdown of the gas with cold electrodes, the voltage across the electrodes will drop a much greater amount than for the hot-electrode operation. Over the current range from 2 to 3 of curve 3, the current will be independent of the voltage, and the voltage drop between the electrodes will be constant regardless of the value of the current. The constant voltage required to maintain conduction will be much greater throughout this range than for hot-electrode C operation. This is because a large portion of the voltage will be required to produce the necessary emission by electric-field emission. The magnitude of the current from 2 to 3 for cold-electrode

operation will be limited to a relatively small value, because only limited emission can be produced from the cold electrode. However, if the current is allowed to increase above the value for point 3 on curve 3, the voltage drop from electrode *C* to *D* will increase as the current increases, as shown from point 3 to 4. The electrodes will be heated by the discharge to a much higher temperature, and liberal emission will take place when point 4 is reached. When the conditions of point 4 are reached, an arc will be produced between the electrodes, and the voltage required to maintain the arc will be very much less than the voltage required to start the arc, and even less than the voltage required throughout range 2 to 3. The conduction characteristic after the arc has been started from point 5 on) will be unstable, *i.e.*, the voltage drop across the electrodes will decrease with increase of the current. So-called cold-cathode tubes operate on the portion of the conduction characteristic from point 2 to 3. Mercury-pool tubes operate in the arc range of the conduction characteristic from point 5 upward.

ELECTRON-TUBE ESSENTIALS AND CLASSIFICATION

6. An electron tube is a device for the purpose of producing, maintaining, and controlling an electric current through a highly evacuated or gas-filled chamber. From the discussion of the preceding sections, any electron tube must have the following essential construction.

1. An enclosing envelope with the enclosed chamber either highly evacuated or containing gas or vapor at low pressure.
2. A conducting element (electrode) fulfilling the following conditions:
   a. Located inside the envelope with a conducting connection to the exterior of the chamber.
   b. So constructed and operated that the electrode will emit electrons into the enclosure.
3. A second conducting element (electrode) fulfilling the following conditions:
   a. Located inside the envelope and separated and insulated from the emitting electrode.
   b. Having a conducting connection to the exterior of the chamber.
   c. So constructed and operated that it will collect electrons emitted by the emitting electrode after they have passed across the enclosure.

The two electrodes listed above are the absolutely essential electrodes required for any electron tube and are designated as the main electrodes. The main electrode that is designed for the emission of electrons is called the **cathode.** The main electrode that is designed for the collection of electrons after they have passed through the space of the tube is called the **anode** or **plate.**

In addition to the absolutely essential main electrodes, an electron tube may have other conducting elements (electrodes) for the purpose of controlling the current between the two main electrodes. These additional electrodes are called **grids.** Each **grid** must be so constructed that

1. It is located inside the envelope.
2. It is separated and insulated from all other electrodes.
3. It is connected by means of a conducting connection to the exterior of the tube.
4. It is so constructed and located as to fulfill the particular desired control function.

7. Requirements for Tube Conduction.—Conduction (the existence of current) can take place in an electron tube only when the following conditions are fulfilled:

1. The cathode is emitting.
2. The anode or plate is at positive potential with respect to the cathode.

8. Rectifier Action of Electron Tubes.—Electron tubes are not the only electronic devices. Several types of lamps (see Div. 10) depend for their operation upon conduction through gas, and these lamps are therefore electronic devices. The lamps, however, are not constructed for the primary purpose of producing, maintaining, and controlling current through the enclosure. Current through the space is essential for their operation, but the primary purpose of the device is to produce light. The gaseous-discharge lamps consequently are not electron tubes as defined in Sec. **6.**

If the emitting electrode in an electronic device becomes positive with respect to the other electrode, the voltage between the electrodes will exert a force tending to drive the electrons back into the emitting electrode, and there can be no current through the enclosure. Electron tubes, with the exception of some cold-cathode tubes, are so constructed that, when the tube is operating properly, only one of the main electrodes will function as a cathode (an emitter of electrons). Therefore, under normal operating conditions, all electron tubes possess rectifying characteristics, *i.e.*, will allow the passage of current in only one direction. The conventional direction of this current is from anode or plate to cathode, and the electronic direction of this current is from cathode to anode. Most electronic lamps (gaseous-discharge lamps), on the other hand, are so constructed that either electrode may become an emitter and function as a cathode while at the same time the other electrode will function as the anode. Most electronic lamps do not possess rectifying characteristics and will allow the passage of alternating current.

If the voltage impressed across the main electrodes of any electron tube is raised to a sufficient value, either electrode may function as a cathode. Too high a voltage across an electron tube will therefore destroy its rectifying characteristics, and it will then pass alternating

current. Electron tubes should never be operated at voltages above their rated value.

9. Classification of Electron Tubes.—Electron tubes may be classified as follows:

A. According to material of enclosing envelope.
  1. Glass.
  2. Metal.

B. According to type of cathode.
  1. Thermionic.
    a. Directly heated.
    b. Indirectly heated.
  2. Mercury-pool.
  3. Cold-cathode.
  4. Photoemissive.

C. According to medium enclosed by envelope.
  1. Vacuum (highly evacuated).
  2. Gas-filled.

D. According to electrodes.
  1. Diode (having simply a cathode and an anode).
  2. Triode (having a cathode, an anode, and one grid).
  3. Tetrode (having a cathode, an anode, and two grids).
  4. Pentode (having a cathode, an anode, and three grids).
  5. Multianode (multipurpose).

10. The enclosing envelope may be formed from either glass or metal. The main advantage of the glass tube is that observation may be made, especially in connection with maintenance, of whether the filament wire is hot or whether ionization of the gas is taking place. The metal tube is less fragile, can be designed smaller in size because it is a better radiator of heat, and forms a natural shield against stray fields.

11. Types of Cathodes.—The different types of cathodes used in electron tubes are listed in Sec. **9.** The cathode must be so constructed and operated that it will function as an efficient emitter of electrons.

Thermionic cathodes or hot cathodes are solid metal cathodes, which in the operation of the tube are heated by a current and produce emission by thermionic means, as described in Sec. **2.** The necessary heating of the cathode may be obtained by the passage of current through the cathode itself (*directly heated cathode*), or an electric heater coil distinct from the cathode may be employed for supplying the necessary heat to the cathode (*indirectly heated cathode*). In either case, the heating current is separate from the current passing from anode to cathode and requires an independent circuit for its production. Both the above types of cathode construction are employed in commercial tubes. Typical cathode constructions are shown in Figs. 6 and 7. The directly heated

cathode is simpler in construction, but the indirectly heated cathode can be constructed to give higher efficiency of emission per watt of heating power employed. The indirectly heated cathode has the advantage that the emitting surface of the cathode can be isolated electrically from the heating circuit. The heating circuit can therefore be supplied with alternating current without the disadvantage of having the variations of the voltage in the cathode-heating circuit affect the main current from anode to cathode.

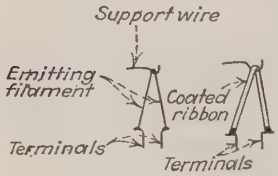


FIG. 6.—Directly heated filament cathodes.

A pool of mercury is employed for the cathode in certain types of gas-filled tubes. Of course, it cannot be used for a high-vacuum tube. The mercury-pool cathode does not require any cathode-heating current, since the emission is produced by the forces exerted by the cathode-anode voltage upon the electrons in the surface of the mercury pool (electric-field emission; see Sec. **2**). No separate cathode-heating circuit is required. The mercury-pool cathode is advantageous for tubes that must handle large amounts of power, since its normal current-carrying possibilities and its overload-current possibilities are inherently high.

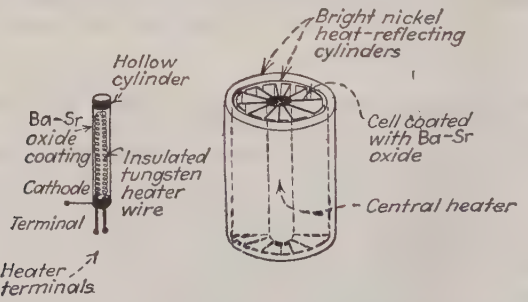


FIG. 7.—Indirectly heated cathodes.

Cold cathodes, as the term is used, are composed of a simple metallic electrode that is not heated by any cathode-heating current. Emission during operation is produced by a very complex phenomenon consisting of a combination of all four of the methods of emission described in Sec. **2**. This type of cathode produces a very limited amount of emission and is therefore satisfactory only for special types of tubes, where very low current capacity is required.

With cold cathodes, no auxiliary means, such as heating of the cathode or incident light on the cathode, are employed to produce emission. Emission is originated by the voltage impressed across the main electrodes (see Sec. **5**).

Photoemissive cathodes are constructed of photoemissive surfaces, as described in Sec. **2.** When the light-sensitive surface of the cathode is energized by impinging light of the proper wave length, electrons are emitted. No cathode-heating circuit is required, since the power required for emission is obtained from the impinging light. This type of cathode is used in phototubes.

12. Medium Enclosed by Envelope.—Electron tubes are of two types, depending upon the medium enclosed by the envelope of the tube. The so-called **vacuum tubes** have the enclosure of the tube evacuated to as high a degree as is practically possible. The other types of tubes contain gas or vapor at a low pressure and are called **gas-filled tubes.** Mercury vapor is employed in a majority of the gas-filled tubes, but inert gases such as argon, neon, and helium are also used.

Vacuum tubes are constructed with either thermionic or photoemissive cathodes, depending upon the purpose of the tube. Common practice is to use the designation vacuum tube principally for the thermionic type of vacuum tube. **Gas-filled tubes** are constructed with thermionic, mercury-pool, photoemissive, or cold cathodes, depending upon the purpose, rating, and characteristics required.

13. Number of Electrodes.—Tubes are classified as in Sec. **9** in accordance with the number of electrodes with which the tube is constructed. The simplest type of tube is the **diode,** which has only two main electrodes, the cathode (emitter) and the anode or plate (the collector). In order to control the anode-cathode current or to alter the operating characteristics, many tubes are constructed with additional electrodes. All electrodes in addition to the cathode and anode are called **grids.** The grid that is used to control the anode-cathode current is called the **control grid,** and the additional grids are called **screen** and **suppressor grids.** The number of grids possessed by tubes of the various electrode designations are given in Sec. **9.** Grids are made of conducting material and usually are constructed in the form of a fine mesh screen, a spiral of wire wound on supporting members, or a perforated cylinder.

14. Multianode tubes are made that are combinations of diodes, diodes with triodes, and diodes with pentodes. They consist of a common cathode and the different sets of anodes or anodes and grids in a single envelope. Each anode, or each anode and its associated grids, functions independently of the other anodes, just as if separate tubes were employed. The common cathode supplies the emission for the various anodes. These multianode tubes are multipurpose tubes, and their sole purpose is for economy and convenience. A multianode tube simply takes the place of as many individual tubes with single anodes as there are anodes in the multianode tube.

15. Table of Tube Symbols.—The symbols employed in wiring diagrams to represent the different types of tubes and their electrodes are shown in Fig. 8.

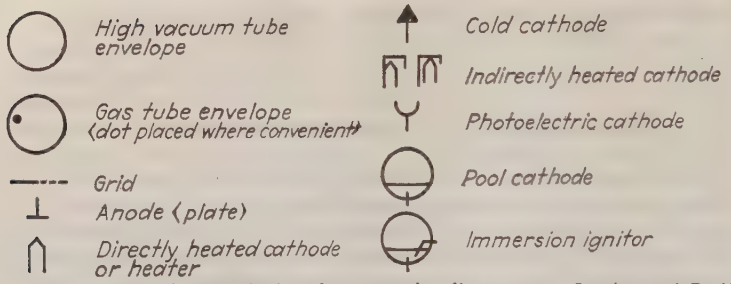


FIG. 8.—Standard symbols for electron-tube diagrams. (*Institute of Radio Engineers.*)

THERMIONIC VACUUM TUBES

16. Diode thermionic vacuum tubes are constructed with both directly and indirectly heated cathodes. An illustration of this type of tube is shown in Fig. 9, and fundamental circuit diagrams are shown in Fig. 10. Unless the impressed voltage is excessive, the tube will allow the passage of current in only one direction, from anode to cathode if conventional direction is considered or from cathode to anode if electronic current direction is considered. The operation of the tube requires two sources of voltage, one for the heating of the cathode and one for the main cathode-anode circuit. The cathode-heating circuit frequently is called simply the cathode circuit and is also designated as the **A** circuit. The cathode-anode circuit frequently is called simply the anode or plate circuit and is commonly designated as the **B** circuit. When the cathode is heated to emission temperature, the tube conducts according to the fundamental vacuum conduction principles of Sec. **3.** The anode-current, anode-voltage characteristic will depend upon the temperature of the cathode. Typical characteristics are shown in Fig. 11. As shown by the figures, for the lower values of voltage, the anode current is practically independent of the cathode temperature, provided that the temperature of the cathode is high enough to give reasonable emission.

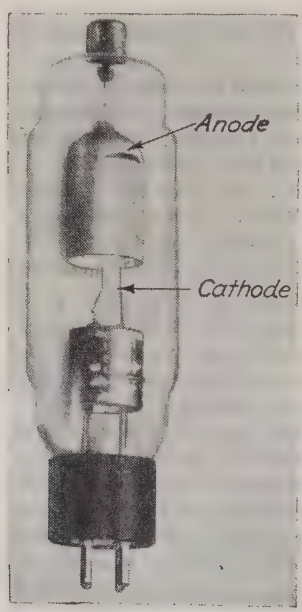


FIG. 9.—Diode vacuum tube. (*General Electric Co.*)

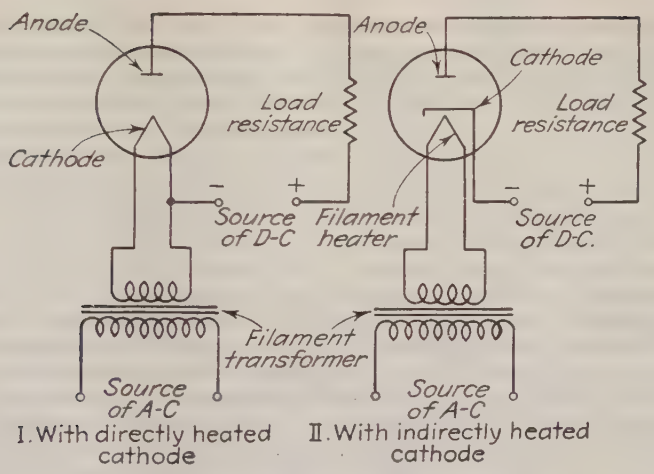


FIG. 10.—Circuit diagrams for diode vacuum tube.

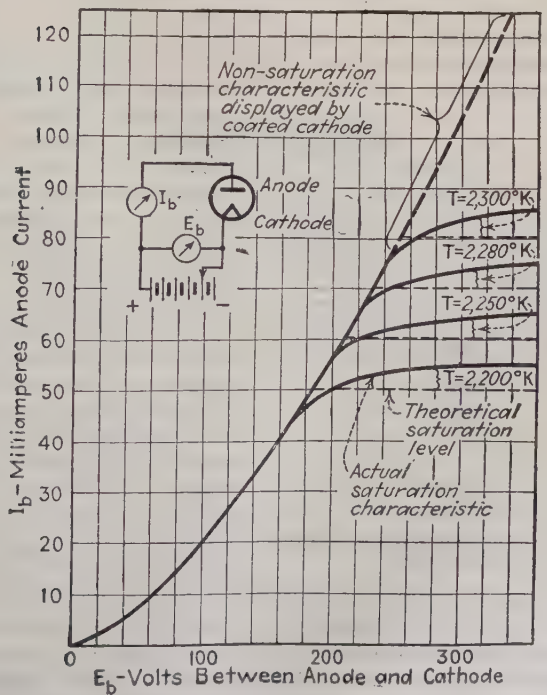


FIG. 11.—Anode current–voltage characteristic curves for a diode vacuum tube.

In the lower portion of the curves, the current is limited by space charge (see Sec. **3**). As the anode voltage is increased, a point will be reached, for each temperature of the cathode, at which the electrons are pulled across to the anode practically as fast as they are emitted. Any further increase in the anode-to-cathode voltage will not materially increase the anode current. In the upper portions of the curves, the current is limited by emission. The voltage drop from cathode to anode varies with the current and the design of the tube and is of relatively high magnitude.

17. Triode thermionic vacuum tubes employ either a directly heated or an indirectly heated cathode. As its name signifies, it has three electrodes: the cathode, the anode, and a control grid. The control grid is located between the cathode and the anode and provides a means for controlling or varying the cathode-anode current without changing the cathode-to-anode voltage. The tube should be operated with rated cathode-heating current so that copious emission will be produced. If the grid is made positive with respect to the cathode, the voltage from cathode to grid will aid the motion of the emitted electrons away from the cathode. Some of these electrons will pass to the grid structure and produce current in the grid circuit. The majority of the electrons, however, will pass through the openings in the grid structure and continue on to the anode under the influence of the higher anode positive potential. A positive grid voltage will therefore increase the anode current for a given anode voltage. On the other hand, if the grid is made negative with respect to the cathode, this voltage from cathode to grid will oppose the motion of the emitted electrons away from the cathode. A negative grid voltage, will therefore, reduce the anode current for a given anode voltage. With a negative grid, the electrons will be repelled from the grid structure, and there will be no grid current. It is usually not advisable to have grid current, so that the tube is generally, operated with a negative grid voltage.

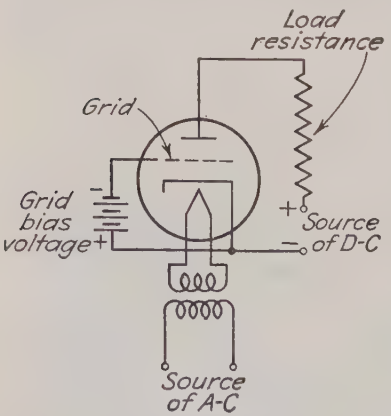


FIG. 12.—Circuit diagram for a triode vacuum tube.

A fundamental circuit diagram is shown in Fig. 12. The operation of the tube requires three circuits: the cathode circuit, the anode circuit, and the circuit from cathode to grid. The cathode-grid circuit, generally, is called simply the grid circuit and is designated as the C circuit.

Typical characteristics of a triode tube are shown in Figs. 13 and 14.

It will be observed from these characteristics that, when the grid is negative, the tube does not always conduct. For a given value of negative-grid voltage, a certain anode voltage is required before there is any anode current. For a given anode voltage, there will be no current until the negative-grid voltage has been reduced to a certain value. These points are called the cutoff points. The effect of the grid on the operation of the tube can be seen from a study of Figs. 13 and 14. It will be observed that the anode current can be completely stopped or varied from zero to the maximum allowable value, simply through variation of the control-grid voltage. From a study of Figs. 13 and 14, it is seen that a given change of grid voltage will produce a greater change in the anode current than will be produced by the same amount of change in the anode voltage. The grid voltage is more effective in controlling the anode current than is the anode voltage. This is an important characteristic of the triode vacuum tube.

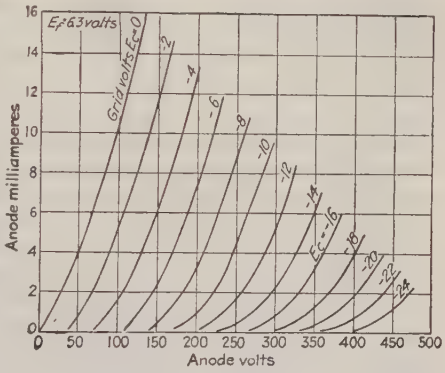


FIG. 13.—Anode current–voltage characteristic curves for a 6J5 triode vacuum tube. (*RCA Mfg. Co.*)

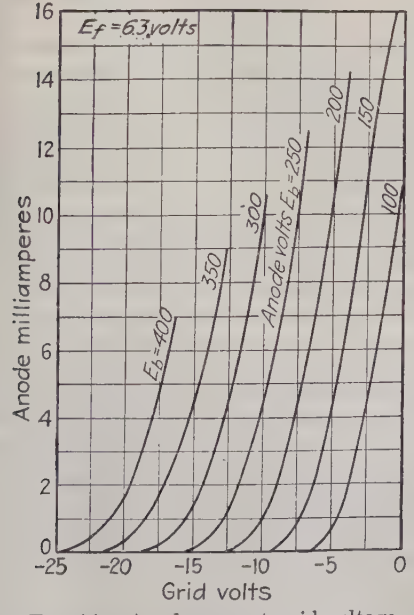


FIG. 14.—Anode current–grid voltage characteristic curves for a 6J5 triode vacuum tube. (*RCA Mfg. Co.*)

The cathode-anode voltage drop varies with the current, the grid voltage, and the design of the tube. This voltage drop is of relatively high magnitude. Unless excessive voltage is impressed in the cathode-anode circuit, the tube will pass current in only one direction.

18. Sources of Grid Voltage. In the operation of a triode vac-

uum tube, it generally is desired to control the anode current by a voltage that originates in some circuit external to the tube circuits. This voltage is called the **signal** voltage or simply the **signal.** The signal voltage may be a direct or an alternating voltage. The desired conditions generally cannot be met by having the entire grid voltage supplied by the signal. Usually the grid circuit is supplied by a constant potential connected in series with the signal voltage. The signal voltage varies the operation of the tube around an operating point established by the constant grid voltage. The constant grid voltage is called the grid-bias voltage or simply the bias voltage. The grid-bias voltage may be obtained from an outside source of e.m.f., or it may be obtained from a grid bias resistor, connected in series with the cathode so that the resistor will be common to both the cathode-anode and the cathode-grid circuits, as shown in Fig. 15. The anode current, in passing through the resistor, produces a voltage drop in such a manner that point *A* in Fig. 15 is made negative with respect to the cathode by the amount of this drop. The voltage drop of the resistor thus acts as a grid bias for the control grid. Since it is desirable to hold the grid bias at as constant a value as possible, it is necessary to connect a by-passing capacitor across the grid-bias resistor. The capacitor will tend to by-pass variations in the anode current around the resistor so that the current through the resistor will stay practically constant.

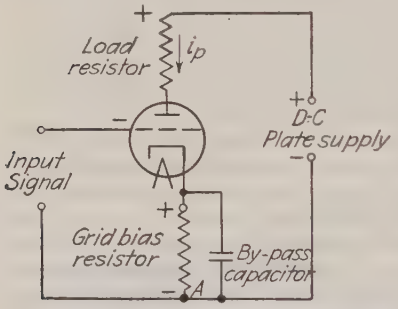


FIG. 15.—Vacuum-tube circuit showing use of grid-bias resistor to produce the negative grid supply voltage.

19. The voltage and current of the plate circuit of a thermionic vacuum tube are usually variable but can be resolved into a steady d-c component and a sine wave varying a-c component. The a-c component of the current is in phase with the a-c component of the voltage. This circuit exhibits the qualities of a resistance, and certain calculations may be made in accordance with Ohm's law. Since the current is usually not proportional to the voltage the resistance is variable in nature, and that fact must be taken into account. The opposition of the tube to the d-c component of voltage is called the **d-c plate resistance.** The opposition to the a-c component is called the **dynamic plate resistance,** or, since this value is much more commonly used than the d-c one, it is shortened to just **plate resistance.**

20. The d-c plate resistance is obtained by dividing the voltage represented by any point on the plate voltage–plate current characteristic by the corresponding current expressed in amperes (Fig. 16). In

making circuit calculations for an amplifier tube, the d-c plate resistance should be computed for the operating point.

$$r_{p_{dc}} = \frac{e_p}{i_p} \tag{1}$$

The voltage is the average value of the plate voltage, and the current is the average value of the plate current.

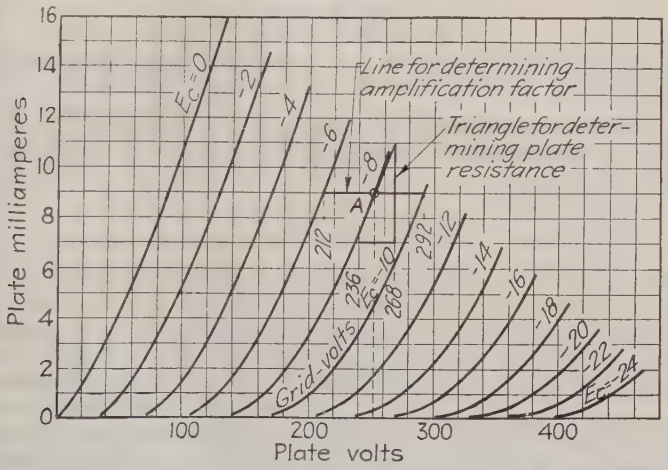


FIG. 16.—Plate current–voltage characteristic curves for a 6J5 triode showing graphical methods for obtaining amplification factor and plate resistance.

Example.—Referring to Table 73 of Div. 11 for the 6J5 tube, the suggested operating point is for a grid voltage of −8 and a plate current of 9 ma. Referring to Fig. 16, these data apply to operating point *A* corresponding to a plate voltage of 252 volts.

$$r_{p_{dc}} = \frac{252}{0.009} = 28{,}000 \text{ ohms}$$

21. The plate resistance (**dynamic plate resistance**) is obtained by drawing a tangent to the plate voltage–plate current characteristic curve at the operating point and constructing a right triangle with the tangent as the hypotenuse (Fig. 16). The change in voltage represented by the length of the base of the triangle expressed in volts divided by the change in plate current represented by the length of the vertical side of the triangle expressed in amperes will be the plate resistance.

$$r_p = \frac{e_{p_2} - e_{p_1}}{i_{p_2} - i_{p_1}} \tag{2}$$

The plate resistance is thus a measure of the opposition to a change in plate current which will be produced by a change in plate voltage. The

plate resistance will be constant for all operating points for which the tangent to the curve makes the same angle with the horizontal. This will occur over quite a wide range of operating points as long as they are not taken too close to the sharply curving portion of the characteristic curves.

Example.—Referring to Fig. 16 and using the triangle with the hypotenuse drawn through points *A*,

$$r_p = \frac{268 - 236}{0.011 - 0.007} = \frac{32}{0.004} = 8{,}000 \text{ ohms}$$

This value checks fairly closely with the value of 7,700 given for tube 6J5 in Table 73 of Div. 11.

22. Mutual conductance of a vacuum tube is a measure of the change in plate current caused by a change in grid voltage, with the plate voltage being held constant.

$$g_m = \frac{i_{p_2} - i_{p_1}}{e_{g_2} - e_{g_1}} \tag{3}$$

The mutual conductance may be obtained by drawing a vertical line on the plate voltage–plate current characteristic graph at the operating point and extending this line to the characteristic curves above and below the operating point (Fig. 16). The length of the line between these characteristic curves measured in milliamperes and changed to amperes is the numerator of the equation. The difference in grid voltage represented by the titles of the two characteristic curves is the denominator of the equation. Since the mutual conductance is always a small decimal when measured in mhos, it is customary to multiply the value by one million in order to express the mutual conductance in micromhos.

Example.—Referring to Table 73 of Div. 11 for the 6SK7 tube, the suggested operating point is 9.2 ma. plate current and 250 plate volts. Referring to Fig. 20, these data apply to operating point *B*.

$$g_m = \frac{(0.0122 - 0.0067)1{,}000{,}000}{-1.5 - (-4.5)} = \frac{0.0055 \times 1{,}000{,}000}{3}$$
$$= 1{,}830 \text{ micromhos}$$

This value checks fairly closely with the value of 2,000 given for g_m for tube 6SK7 in Table 73 of Div. 11.

23. The amplification factor of a tube gives a measure of the relatively greater effect of a change in **grid** voltage on the plate current of a vacuum tube compared with a change of **plate** voltage.

$$\mu = \frac{e_{p_2} - e_{p_1}}{e_{g_2} - e_{g_1}} \tag{4}$$

The amplification factor may be obtained by drawing a horizontal line on the plate voltage–plate current characteristic graph at the operating point (Fig. 16). Take two points on this line, preferably at the

intersection with the curves or at an easily estimated fraction between them. The difference in plate voltage represented on the plate-voltage scale between these two points is the numerator of the equation. The difference in grid voltage represented by these two points, interpolated between the curves if required, is the denominator of the equation.

Example.—Referring to the horizontal line through point *A* in Fig. 16, running from $e_g = -6$ to $e_g = -10$

$$\mu = \frac{292 - 212}{-10 - (-6)} = \frac{80}{-4} = -20$$

This checks exactly with the value of 20 given for the 6J5 tube in Table 73 of Div. 11. The minus sign merely indicates that the grid voltage is changed in a direction opposite to that of the plate voltage.

The relationship among amplification factor, plate resistance, and mutual conductance is given by Eq. (5).

$$\mu = r_p \times g_m \tag{5}$$

This can be proved as an identity as follows, by substituting for each of the terms its equal from the previous equations:

$$\frac{e_{p_2} - e_{p_1}}{e_{g_2} - e_{g_1}} = \frac{e_{p_2} - e_{p_1}}{i_{p_2} - i_{p_1}} \times \frac{i_{p_2} - i_{p_1}}{e_{g_2} - e_{g_1}} \tag{6}$$

The difference in plate currents will cancel out, leaving both sides of the equation equal.

24. The values for amplification factor, plate resistance, and mutual conductance for vacuum tubes for the usual operating points may be obtained from tables of tube-characteristic data such as are given in Table 73 of Div. 11. The tube manuals published by the manufacturing companies and carried in stock by radio supply stores give these curves for most tubes.

25. Tetrode thermionic vacuum tubes are frequently called **screen-grid tubes.** They are constructed with four electrodes: the cathode, the anode, and two grid electrodes. The circuits and arrangement of the grids are shown in Fig. 17. The grid located close to the cathode is a control

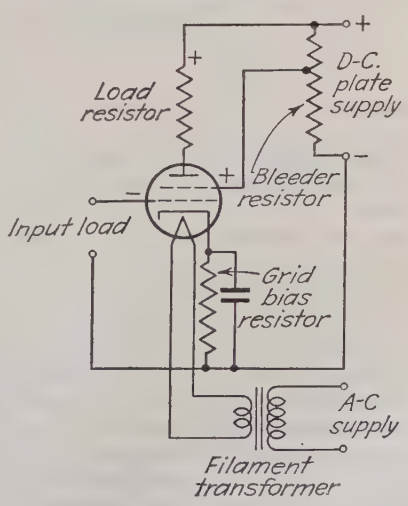


FIG. 17.—Circuit for a vacuum screen-grid tube.

grid and functions in the same manner to control the anode current as does the control grid of the triode tube. The second grid, or screen grid, as it is called, is located between the control grid and the anode. The screen grid is operated at a positive potential with respect to the cathode, somewhat lower in value than the anode potential with respect to the cathode. The addition of the screen grid alters the

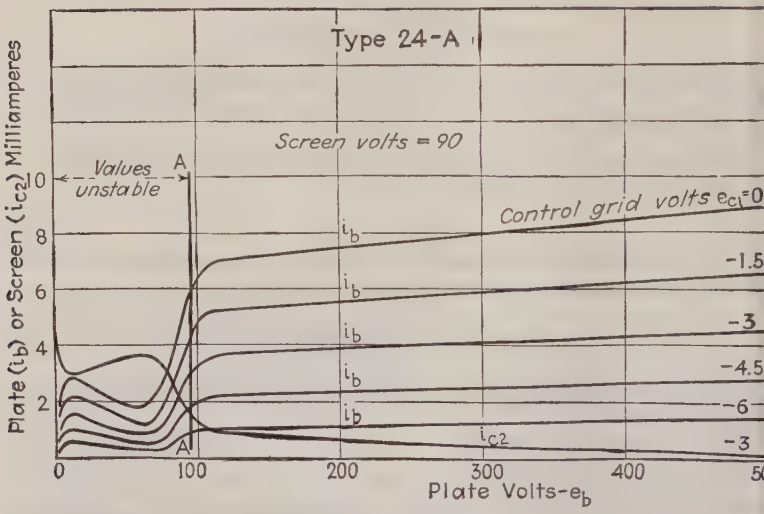


FIG. 18.—Plate current–voltage characteristic curves for a screen-grid tube.

characteristics of the tube in two ways: (1) it reduces the capacitance of the capacitor formed by the control grid and anode, and (2) it tends to shield the anode from the cathode and thereby makes the anode less effective in attracting electrons from the cathode. These two effects make it possible to design tetrodes with much higher amplification factors (μ) than is possible with triodes.

The operation of a tetrode involves four circuits: the cathode circuit, the anode circuit, the control-grid circuit, and the screen-grid circuit.

Typical characteristics for a tetrode are shown in Fig. 18. The tube should always be operated with an anode voltage that will cause operation on a portion of the curve to the right of the vertical line *A* in Fig. 18. Operation in the lower regions of the curves is unstable. The cathode-anode voltage drop varies with the current, the grid-control voltage, the screen-grid voltage, and the design of the tube. This voltage drop is of relatively high magnitude. The amplification factor, plate resistance, and mutual conductance of tetrodes have the same significance and are determined in the same manner as for triodes.

26. The pentode thermionic vacuum tube has three grids in addition to the main electrodes of cathode and anode. These grids are called, respectively, the control grid, the screen grid, and the suppressor grid. A fundamental circuit diagram is shown in Fig. 19. The operation of the tube involves five circuits: the cathode circuit, the anode circuit, the control-grid circuit, the screen-grid circuit, and the suppressor-grid circuit. The suppressor grid usually does not require a separate source of voltage, since it is generally connected directly to the cathode and therefore operates at the same potential as the cathode.

The control grid is located close to the cathode and performs the same function of controlling the anode current as in the triode and tetrode tubes. The suppressor grid is located close to the anode and is connected externally to the tube and directly to the cathode. The negative potential, with respect to the anode, of the suppressor grid repels any electrons that are liberated from the anode by secondary emission and drives them back to the anode. This suppression of the anode secondary emission eliminates one of the limitations of the tetrode tube. In the tetrode tube, electrons, liberated at the anode by secondary emission, caused by bombardment of the anode by the electrons coming from the cathode, are attracted to the screen grid. The resulting current of electrons from anode to screen grid reduces the effective anode current. The screen grid of the pentode tube is located between the control and suppressor grids and performs the same functions as in the tetrode tube. It is energized by a voltage positive with respect to the cathode but of smaller magnitude than the anode voltage.

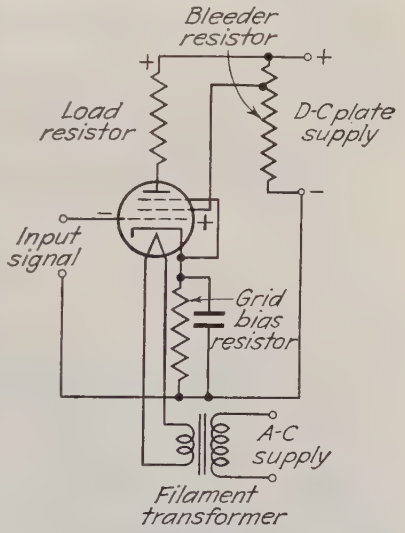


FIG. 19.—Circuit for a pentode vacuum tube.

Typical characteristics for a pentode are shown in Fig. 20. The cathode-anode voltage drop varies with the anode current, the grid-control voltage, the screen-grid voltage, and the design of the tube. This voltage drop is of relatively high magnitude. The amplification factor, the anode, or plate, resistance, and the conductance of pentodes have the same significance and are determined in the same manner as for triodes.

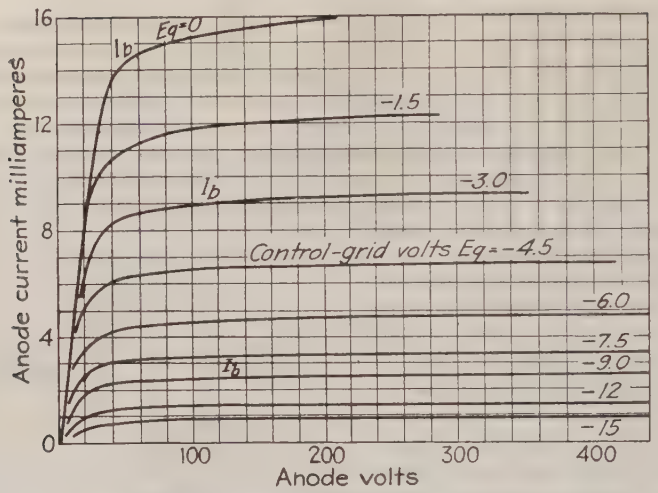


FIG. 20.—Anode current–voltage characteristic curves for a 6SK7 pentode vacuum tube. (*RCA Mfg. Co.*)

27. X-ray Tubes.—The first electronic device to be put to practical use was the X-ray tube. In the intervening years, it has been perfected and improved to a marked degree. The present-day X-ray tube (see Fig. 21) is a special thermionic vacuum diode with a tungsten cathode and an anode of very rugged construction so that it can withstand the heavy electron bombardment to which it is subjected. The tube is constructed to operate with a very high cathode-to-anode potential, varying for different tubes from 10,000 to 1,000,000 volts. Because of the high cathode-to-anode potential, the electrons emitted by the cathode are rapidly accelerated in their motion toward the anode. When the electrons strike the anode, they have reached a velocity approaching that of light and consequently have acquired a high kinetic-energy level. This energy is sufficient to cause the electrons to penetrate into the atoms of the material of which the target of the anode is constructed. The penetration of the high-energy-level electrons into the target atoms produces an energy transition. This energy transition results in the emanation of electromagnetic waves of very high frequency and corre-

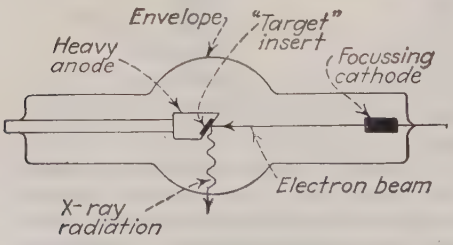


FIG. 21.—X-ray tube.

sponding short wave length. These very high frequency electromagnetic waves are called X rays and have the ability to penetrate several inches into any material they strike. Their penetrating power increases as the cathode-to-anode voltage of the producing tube is increased. The X-ray tube has been used for a long time for medical and scientific purposes. More recently it has been applied to industrial applications such as analysis of metal structure, examination of finished products, revealing of internal flaws in castings, and detecting the presence of foreign materials in packaged goods.

28. Equivalent Circuits for Vacuum Thermionic Tubes.—The output or load of a vacuum thermionic tube is located in the cathode-anode circuit. The great majority of practical calculations, therefore, are for the cathode-anode circuit. The resistance characteristics of this circuit

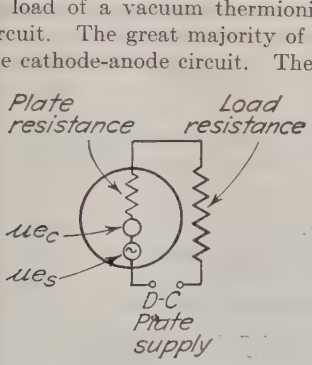


FIG. 22.—Equivalent circuit for an amplifier tube.

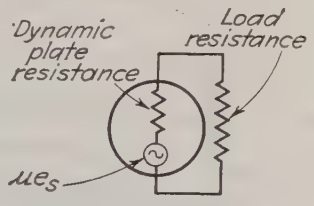


FIG. 23.—Dynamic equivalent circuit for an amplifier tube.

were discussed in Secs. **19** to **21.** Any voltage in the control-grid circuit affects the cathode-anode current. Insofar as its effect on the cathode-anode circuit is concerned, a voltage in the control-grid circuit can be replaced by a voltage directly in series with the cathode-anode circuit. From Sec. **23** it is seen that this equivalent voltage in the cathode-anode circuit will have a value equal to the actual control-grid voltage times the amplification factor (μ) of the tube. For calculation purposes, therefore, the actual cathode-anode circuit can be replaced by the equivalent circuit of Fig. 22. In the majority of calculations, it is desired to determine the effect of the signal voltage on the load element of the anode circuit. In these cases, the d-c component of voltage and current can be neglected and only the varying or dynamic ones considered. For calculations of the dynamic characteristics of the cathode-anode circuit, the equivalent circuit of Fig. 23 is employed. In determining the values of the characteristics of the equivalent dynamic circuit, the following rules must be observed:

1. The amplification factor, employed to determine the equivalent anode-circuit voltage, must be the amplification factor of the tube for the grid bias voltage, the voltages of the other grids, and the cathode-

anode voltage employed in the actual circuit. The cathode-anode voltage used to determine the amplification factor will not be the anode-circuit supply voltage but will be the anode-circuit supply voltage minus the voltage drop in the load.

2. The cathode-to-anode resistance of the tube must be the dynamic anode resistance for the grid bias voltage, the voltages of the other grids, and the cathode-anode voltage employed. The d-c or ordinary resistance of the anode must not be used in the equivalent dynamic circuit.

29. The load line is a line that can be drawn on the plate voltage–plate current graph to study the operation of a vacuum tube as an amplifier.

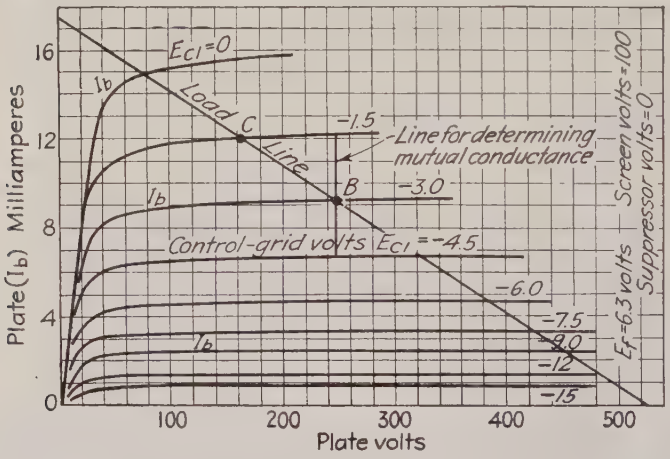


FIG. 24.—Plate current–voltage characteristic curves for a 6SK7 pentode showing a load line.

In using the tube as an amplifier, a load impedance r_L is connected in series with the plate, across the plate supply voltage E_B. The plate voltage e_p under any operating condition is then expressed by Eq. (7).

$$e_p = E_B - i_p r_L \tag{7}$$

This means that the plate voltage is less than the supply voltage by the amount of voltage drop in the load. When the load is a resistance, as it is in the majority of cases, values of e_p and i_p that satisfy Eq. (7) plot as a straight line. The most convenient way to draw this line (Fig. 24) is to obtain two points, one by letting $i_p = 0$ and solving for the corresponding value of e_p; the other by letting $e_p = 0$ and solving for the corresponding value of i_p. Then draw the straight line between them. In doing this, E_B and r_L must be known, having been previously selected or assumed if this is just a study. Any point on the load line is a possible operating condition, provided that the grid voltage is made the correct value.

Example.—Referring to Fig. 24 and using an $E_B = 525$ v and $r_L = 30{,}000$, for $i_p = 0$, $e_p = E_B = 525$ volts; for $e_p = 0$, $i_p = \frac{E_B}{r_L} = \frac{525}{30{,}000} = 0.0175$ amp. These points are located at the points where the load line crosses the respective axes.

The load line may be used to determine the operating conditions of the tube under any signal input. Referring to the data of the above example and to Fig. 24, if a signal of +1.5 volts is impressed on the grid in series with a −3.0 volt bias, the net grid voltage will be $-3.0 + 1.5 = -1.5$ volts. The intersection of the load line with the −1.5 characteristic curve at point *C* indicates that the plate current will then be 12 ma. and the plate voltage will be 162 volts.

30. Thermionic vacuum tubes are rated in filament voltage and current; average value of plate current; average value of plate voltage; and, in the case of amplifier tubes, power output and amplification factor. In selecting a tube, it is important to see that the filament voltage is one that will be available from the power transformer. The standard ratings are 2.5, 6.3, 12, 50, and 117 volts. If the filaments of all the tubes in a chassis are to be in parallel, they must have the same voltage. If they are to be in series, they must be rated for the same current, and the sum of their voltage ratings must equal the supply voltage. If the tube is to operate a relay, the plate current must be of a value that will be suitable for the relay coil. If the tube is to operate a speaker, the power output must check with the speaker rating. The direct current available from the power supply must be higher than the plate voltage recommended in order that the tube will have the correct plate voltage after allowing for the *IZ* drop in the load. The amplification factor should be large enough for the purpose for which the tube is to be used. It should be especially large for the first or second stage of an amplifier.

THERMIONIC GAS-FILLED TUBES

31. Diode thermionic gas-filled tubes are made in two general types, differing from each other in the amount of pressure employed in the enclosure of the tube. Those in the lower pressure range are known as **phanotrons** and those in the somewhat higher pressure range as **tungar,** or **rectigon,** tubes.

Phanotrons are constructed with either directly or indirectly heated cathodes. Indirectly heated cathodes are used in a majority of these tubes, especially in tubes of the higher current ratings. The gas most commonly used is mercury vapor, which is obtained from a small amount of mercury sealed within the tube. The pressure inside the tube enclosure of these mercury-vapor tubes varies with the temperature of the tube. The operating characteristics of the tube will therefore vary somewhat with the temperature of operation of the tube, unless the tube is immersed in an oil bath controlled for constant-temperature operation. Where the temperature effect of mercury-vapor tubes is objectionable,

tubes containing an inert gas are employed. Gases commonly used in these tubes are argon, neon, and helium. A typical phanotron is shown in Fig. 25, and a fundamental circuit diagram in Fig. 26. Two sources of voltage are required, one for the cathode-heating circuit and one for the main cathode-anode circuit.

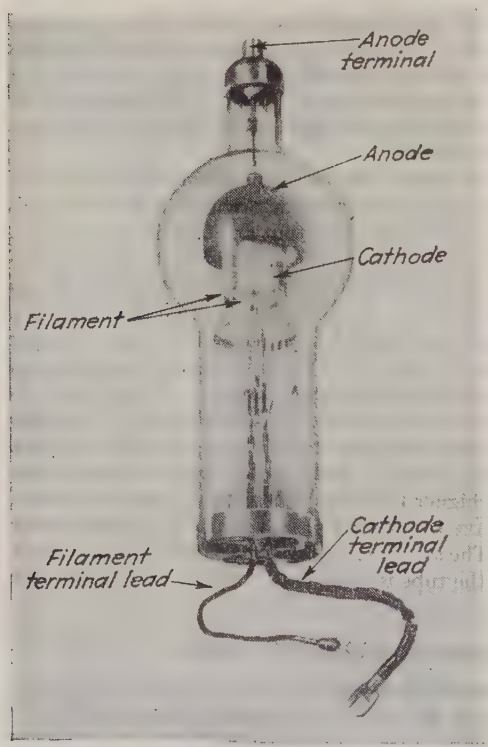


FIG. 25.—Phanotron gas-filled tube. (*General Electric Co.*)

Two precautions must be taken in the operation of phanotron tubes: (1) the cathode-anode circuit must not be closed until the cathode has been brought up to operating temperature, and (2) sufficient impedance to limit the cathode-anode current to a safe value must always be inserted in the anode circuit. If the cathode is not at emitting temperature before the anode circuit is closed, the vapor will ionize, and emission will be produced at the cathode by bombardment of the cathode by positive ions. This bombardment will ruin the cathode.

When voltage is applied from cathode to anode and the cathode is heated to emission temperature, there will be no conduction of any appreciable magnitude through the tube until the cathode-anode voltage has been raised to the breakdown voltage of the gas (see Sec. 5). When the applied voltage is above the breakdown voltage, the gas will be ionized, and the tube will pass current until the cathode-anode voltage is lowered to a value below the voltage drop of the tube. Unless excessive reverse voltage is applied from cathode to anode, the tube will conduct in only one direction and will have rectifying characteristics.

The voltage drop from cathode to anode in phanotron tubes is relatively low compared with that for diode vacuum tubes. The voltage drop is

practically independent of the current for inert-gas tubes and also is practically independent of the current for mercury-vapor tubes, provided that the operating temperature of the tube is held constant. In mercury-vapor tubes, the voltage drop will vary from 6 to 12 volts depending upon the temperature of the tube. In neon and helium tubes, the voltage drop with the pressure employed will be from 20 to 25 volts; and, in argon tubes, the voltage drop with the pressure employed will be from 8 to 10 volts. Because of the relatively low and constant voltage drop, it is always necessary to have sufficient impedance inserted in the anode circuit of phanotrons to limit the anode current to a safe value.

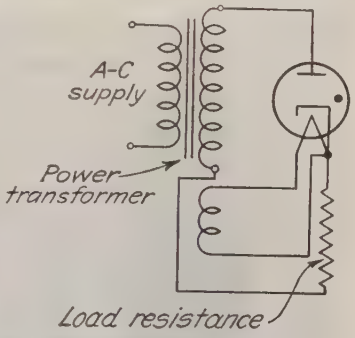


FIG. 26.—Circuit for a phanotron tube.

The tungar, or rectigon, tubes employ directly heated coated tungsten cathodes and an inert gas, usually argon. The pressure employed is considerably greater than that which is employed in phanotrons. The tungar, or rectigon, tubes are suitable only for relatively low-voltage circuits and are employed principally for battery-charging rectifier service. The principles of their operation and their general characteristics are similar to those of the phanotrons.

32. Triode thermionic gas-filled tubes are known as **thyratrons.** Their construction is similar to that of phanotron tubes with the addition of a control-grid electrode (Fig. 27). The phanotron tubes pass only a very small current until the anode potential is high enough to break down and ionize the gas. After ionization, the current increases suddenly to a much higher value. It is often desirable to control the breakdown of the gas without changing the cathode-anode potential. This control of the breakdown of the gas can be obtained in the triode tube by means of the control grid, which is located between the cathode and the anode. When the grid is negative with respect to the cathode, force will be exerted by this grid voltage, tending to impede the acceleration of the electrons as they are emitted from the cathode. This opposition will require a higher cathode-anode voltage to produce breakdown of the gas and start normal conduction through the tube. With a definite anode voltage, if the grid is supplied with the proper voltage, breakdown of the gas and normal conduction will be prevented. If the grid is made positive, force will be exerted by this grid voltage tending to aid the acceleration of the electrons as they are emitted from the cathode, and a positive grid will therefore aid the anode voltage in breaking down the gas and producing

normal conduction. In this type, unless the grid is made positive with respect to the cathode, the anode voltage will be unable to produce breakdown of the gas. Typical grid-control starting characteristics or breakdown characteristics are shown in Figs. 28 and 29. Some thyratrons are designed for control of breakdown through positive-grid control voltage and others are designed for control of breakdown through negative-grid control voltage.

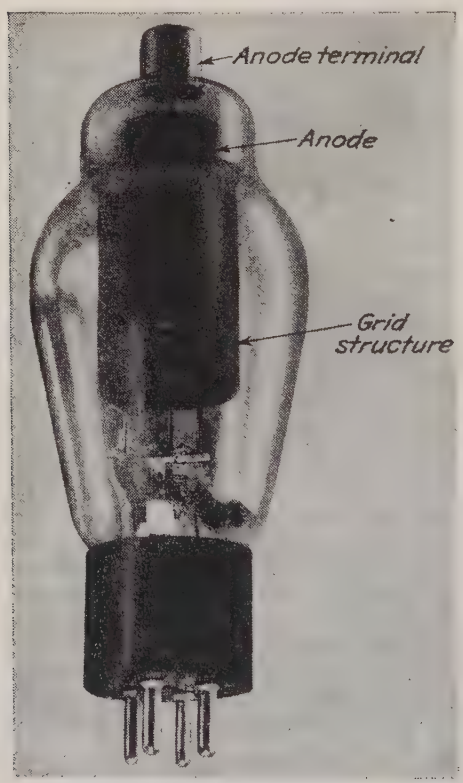


FIG. 27.—Thyratron gas-filled tube. (*General Electric Co.*)

Operation of a thyratron requires three circuits, as shown in Fig. 30: the cathode-heating circuit, the cathode-anode circuit, and the control-grid circuit. The same precautions must be observed in the operation of thyratrons as are stated in Sec. **31** for the operation of phanotron tubes. A resistor should be connected in series with the grid to limit grid current. When voltage is applied from cathode to anode and the cathode is heated to emission temperature, there will be no conduction of any appreciable magnitude through the tube until the cathode-anode voltage has been raised to the voltage that is required to break down the gas with the particular grid-control voltage that is applied to the grid. As stated previously, the value of the anode-cathode voltage required to produce breakdown will be controlled by the value and polarity of the grid-control voltage. When the applied cathode-anode voltage is above breakdown, the gas will be ionized and the tube will pass current until the cathode-anode voltage is lowered to a value below the voltage drop of the tube. The grid voltage has no control over the anode current once the gas has broken down and conduction has started. Unless excessive reverse voltage is applied from cathode to

anode, the tube will conduct in only one direction and will have rectifying characteristics.

The voltage drop from cathode to anode is relatively low and is practically independent of the current for inert-gas tubes and also is practically independent of the current for mercury-vapor tubes, provided that the operating temperature of the tube is held constant. The voltage-drop characteristics are practically the same as for phanotron tubes (see Sec. **31**). As with phanotron tubes, because of the relatively low and constant voltage drop, it is always necessary to have sufficient impedance inserted in series with the anode circuit so as to limit the anode current to a safe value.

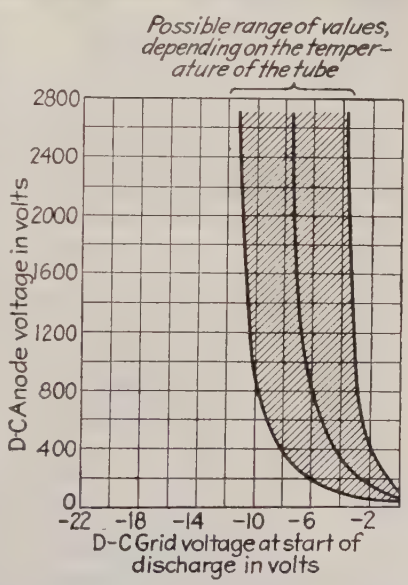


FIG. 28.—Negative breakdown characteristics for an FG-17 thyratron. (*General Electric Co.*)

In the triode vacuum tube, the magnitude of the anode current is controlled by the magnitude and polarity of the control-grid voltage. This is not true in the thyratron tube. The grid in the gas tube will control the starting of conduction in the tube but has no control over the instantaneous anode current once ionization of the gas has been initiated and conduction has started. This lack of control by the grid over the magnitude of the instantaneous anode current is caused by the following action: As soon as the tube conducts, charged ions are attracted to the grid and form a sheath of charged ions around the grid structure. This sheath of ions, which will be of polarity opposite to that of the grid structure, shields the grid from the rest of

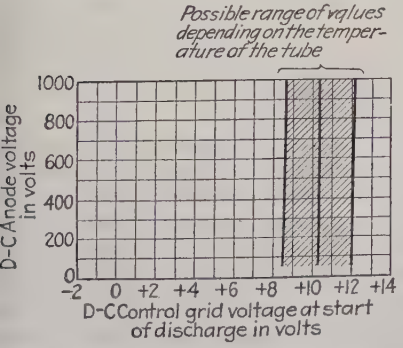


FIG. 29.—Positive breakdown characteristics for an FG-33 thyratron. (*General Electric Co.*)

the tube and renders the grid inactive with respect to the cathode-anode circuit.

Although the grid has no control over the magnitude of the instantaneous anode current, when a-c voltage is applied to the anode circuit, the *average* anode current can be controlled by controlling the period of conduction during each positive half cycle. With zero grid potential, anode current will start as soon as the anode voltage reaches a positive value equal to the breakdown voltage of the gas. Current will continue to flow until the voltage across the tube drops below the voltage drop of the tube. During the half cycle when the anode is negative, no current

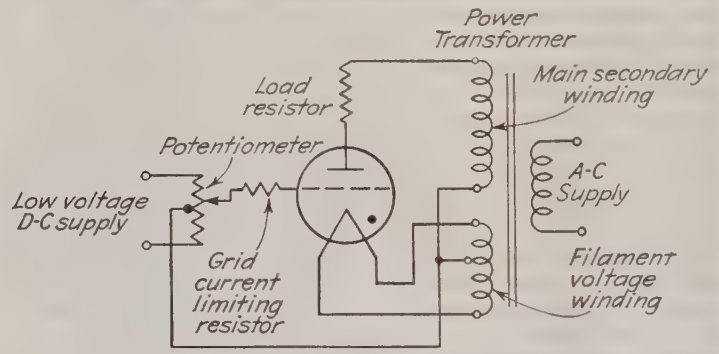


FIG. 30.—Circuit for a thyratron gas-filled tube.

will flow because of the rectifying characteristic of the tube. If the grid is made somewhat negative, the anode current will not start until the anode voltage has reached a higher positive value than that which started conduction with zero grid voltage. The tube will therefore conduct for a smaller portion of the positive half cycle. The average value of the anode current will thereby be reduced. The fundamentals of the control of the average anode current under a-c operation are shown in Fig. 31. Further discussion of this control is given in Sec. **33.**

33. Control of Thyratrons.—Circuits for controlling the breakdown, or firing, as it is often called, of thyratron tubes may be divided into two general classes: (1) trigger or amplitude control circuits and (2) phase-shift control circuits. With direct voltage applied to the cathode-anode circuit, only amplitude control can be applied. With alternating voltage applied to the cathode-anode circuit, either one of the methods may be used. When direct voltage is applied to the cathode-anode circuit, the tube will break down whenever the grid voltage is made more positive (less negative) than is required to prevent breakdown and then will continue to pass current no matter what is done to the grid voltage. In order to stop conduction and reduce the anode current to zero, either the anode voltage must be reduced to practically zero or the anode cir-

cuit must be opened by some switching means. When alternating voltage is applied to the cathode-anode circuit, the grid will regain control every time the anode voltage becomes negative, since this will stop conduction in the anode circuit and require breakdown of the tube during each positive half cycle. The average current delivered to the load by a thyratron tube operated on alternating current can be controlled by controlling the time during which current flows in each cycle. With trigger control, the period of conduction of the tube can be gradually controlled from conduction throughout practically all of each positive half cycle to conduction throughout practically one-half of each positive half cycle, but no control of conduction can be obtained throughout the last half of each positive half cycle. Conduction can be entirely prevented, of course, by a sufficiently negative grid. With phase-shift control, the period of conduction can be gradually controlled from conduction throughout practically all of each positive half cycle down to the zero conduction period. Trigger control may employ either direct or alternating voltage for the supply to the grid circuit. Phase-shift control requires an alternating voltage for the supply to the grid circuit.

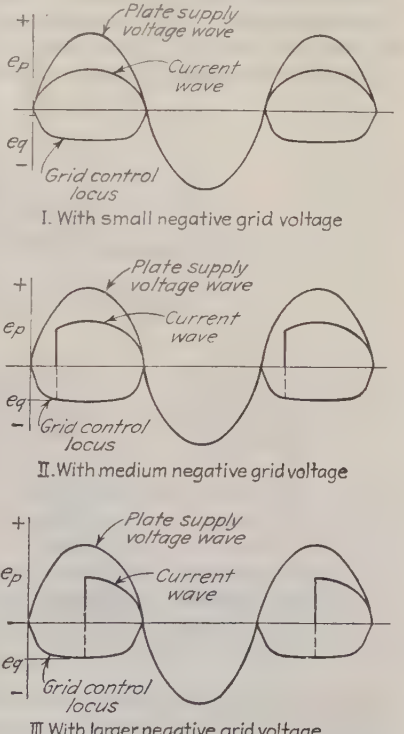


Fig. 31.—Wave diagrams showing the principle of control of the average current with a thyratron tube, employing d-c amplitude control of grid voltage.

The fundamentals of phase-shift control can be understood from a study of Fig. 32. In part I of the figure, a grid-control locus curve is plotted for a given a-c anode voltage. The values for plotting this curve are obtained by taking instantaneous values of the anode voltage and determining from the breakdown characteristic of the tube the grid voltage that will just allow breakdown for each value of the anode voltage. From the curves of I, the breakdown point in each positive half

cycle can be determined for any alternating voltage impressed on the grid. In part II of the figure, an alternating voltage which is 170 degrees out of phase with the anode voltage is impressed on the grid. Since at all instants of time throughout the positive half cycle of the anode voltage the grid voltage is more negative than the critical grid voltage, the tube will be prevented from breaking down at any time. Conduction in the anode circuit will be entirely prevented, and the anode current will be zero. In part III of the figure, an alternating voltage which is in phase with the anode voltage is impressed on the grid. Under these

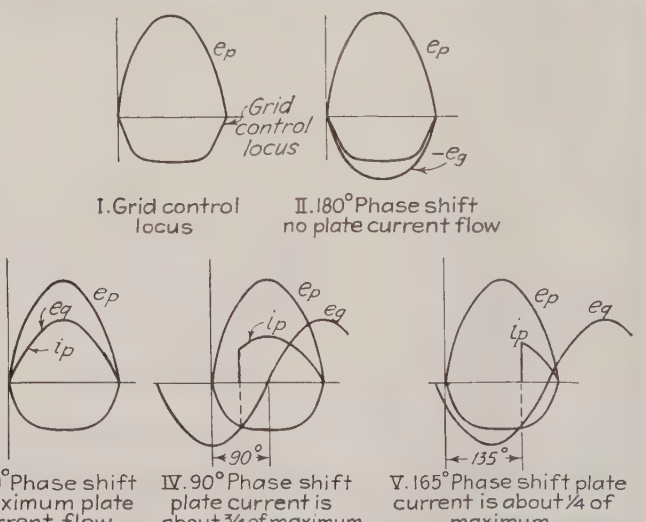


FIG. 32.—Wave diagrams showing phase-shift control of the average current of a thyratron tube.

conditions, the tube will break down as soon as the anode voltage reaches a positive value equal to the breakdown voltage of the gas of the tube. This phase relationship of the grid voltage will give maximum length of conduction, and the tube will conduct throughout practically all of the positive half cycle of the anode voltage. In part IV of the figure, the grid voltage is adjusted so that it lags the anode voltage. The tube will break down at the instant that the grid-voltage curve crosses the grid-control locus curve, with the grid voltage decreasing in negative magnitude. The tube will then conduct for only a portion of the positive half cycle of the anode voltage, and the average value of the anode current will be something less than the maximum amount obtained for conditions of part III of the figure. In part V of the figure, the grid voltage is made to lag the anode voltage by a greater amount than for

the conditions of part IV of the figure. The tube then will not break down until a later point in the positive half cycle of the anode voltage than for part IV, and the average value of the anode current will be less than it was for IV. As the angle of lag of the grid voltage is increased toward 180 degrees, the breakdown point will come later and later in the positive half cycle of the anode voltage, and the average anode current will be reduced until it reaches zero when the grid voltage is nearly 180 degrees lagging. Thus, with phase-shift control, the conduction period of the tube can be controlled from conduction throughout practically all of the positive half cycle of the anode voltage to zero conduction, and the average value of the anode current can be gradually controlled from its maximum possible value down to zero.

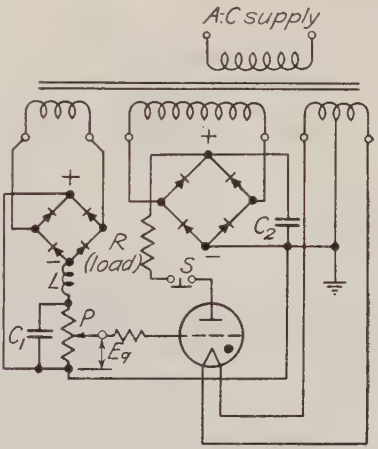


FIG. 33.—Control circuit for a thyratron tube with d-c anode voltage and d-c amplitude control.

A control circuit for operation of a thyratron with direct anode voltage is shown in Fig. 33. The complete circuit is operated from an a-c supply with direct current supplied to the grid and anode circuits by means of bridge-connected contact rectifiers. The grid supply is filtered by means of the L-type inductance-capacitance filter (see Sec. **49**). The anode supply is filtered by the capacitance filter C_2. The grid voltage can be adjusted in magnitude by the potentiometer P. When switch S is open, no conduction can take place, and the anode current is zero. With switch S closed, the tube will fire or be prevented from firing, depending upon the setting of the potentiometer P.

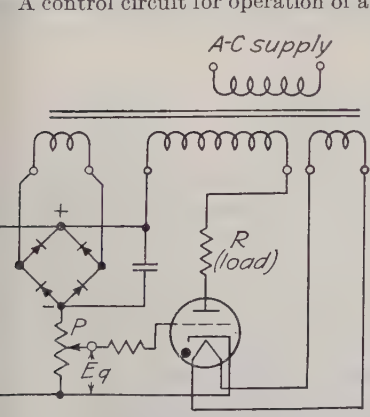


FIG. 34.—Control circuit for a thyratron tube with a-c anode voltage and d-c amplitude control.

A d-c trigger or amplitude-control circuit for operation of a thyratron

with a-c anode voltage is shown in Fig. 34. The variable direct grid-control voltage is obtained through the potentiometer P, which is energized from a bridge-connected contact rectifier. The capacitor acts as a filter to smooth out the ripple in the d-c supply to the potentiometer. Other means of obtaining the variable direct voltage for the grid circuit are a phototube supplied from a bridge-type rectifier, a grid-controlled amplifier tube, the voltage drop across a resistor, and the armature voltage of a small d-c generator. An a-c trigger-control circuit is shown in Fig. 35.

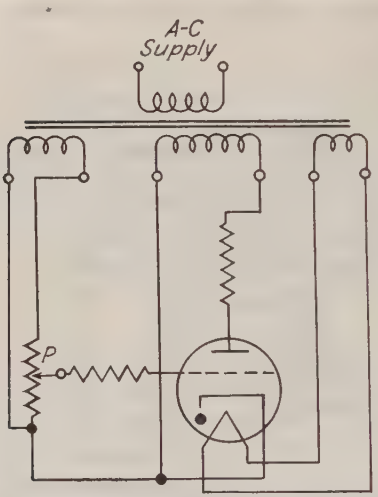


FIG. 35.—Control circuit for a thyratron tube with a-c anode voltage and a-c trigger control.

Three of the numerous circuits for producing phase-shift control are shown in Figs. 36, 37, and 38. In the circuit of Fig. 36, phase shift of the grid voltage is obtained from a bridge circuit employing a variable resistor and a capacitor. When the resistance R is zero, the grid voltage E_g is in phase with the anode voltage E_b. As the value of

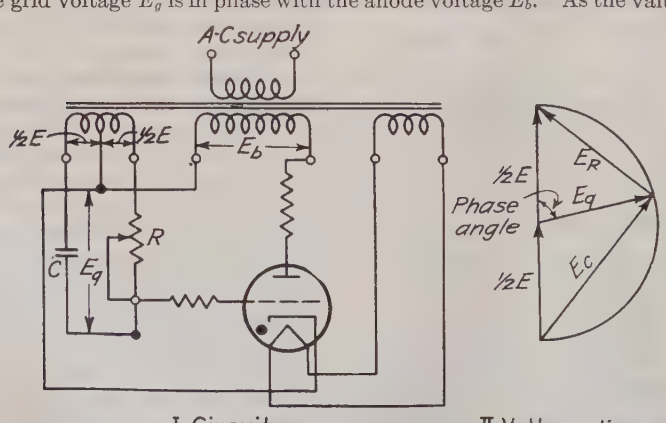


FIG. 36.—Control circuit for a thyratron tube using phase-shift control obtained from a variable resistance-capacitance bridge.

the resistance R is increased, the grid voltage is made more lagging with respect to the anode voltage, and the average anode current of the thyra-

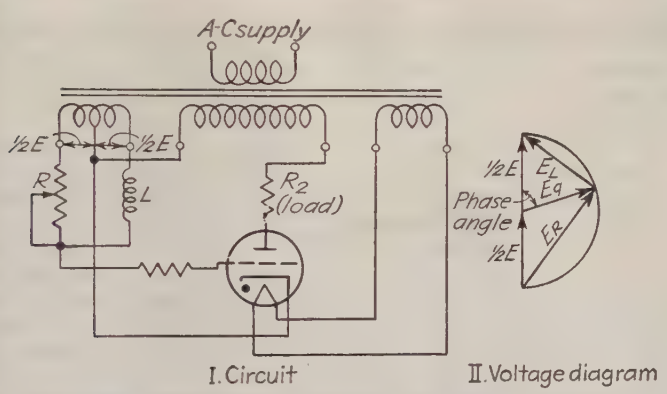


FIG. 37.—Control circuit for a thyratron tube using phase-shift control obtained from a variable resistance-inductance bridge.

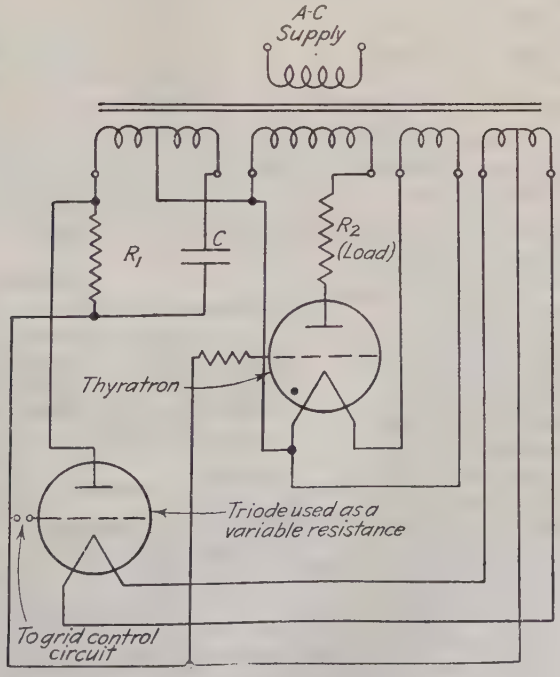


FIG. 38.—Control circuit for a thyratron tube using phase-shift control obtained from an amplifier-capacitor bridge.

tron is consequently decreased. In the circuit of Fig. 37, phase shift of the grid voltage is obtained by means of a bridge circuit employing an inductive reactor and a variable resistor. When the resistance R is zero, the grid voltage is 180 degrees out of phase with the anode voltage. As the value of the resistance R is increased, the grid voltage is made less lagging with respect to the anode voltage, and the average anode current of the thyratron is increased. In an R-L bridge circuit, the control of the amount of phase shift is often obtained by means of a fixed resistance in one arm of the bridge and a variable inductive reactance in the other arm. A convenient means of varying the inductive reactance is by means of a saturable-core reactor. Refer to Sec. **178** of Div. 5 for an explanation of a saturable-core reactor and to Sec. **140A** of Div. 7 for an application of a phase-shift circuit employing a saturable-core reactor.

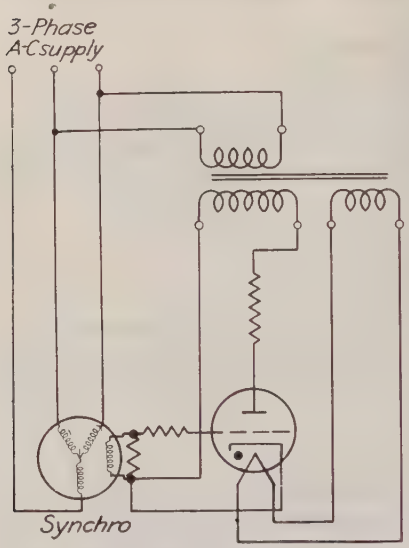


FIG. 39.—Control circuit for a thyratron tube using phase-shift control obtained from a synchro.

It is often desirable to control the phase shift through electronic means. One method of obtaining electronic phase-shift control is by varying the resistance of a phase-shift bridge circuit by means of a triode vacuum tube, as shown in Fig. 38. The anode circuit of the triode vacuum tube is in parallel with the resistance arm of the bridge R, C. As the grid voltage of the vacuum tube is made more positive. the resistance of the anode circuit of the tube is decreased. This decreases the total

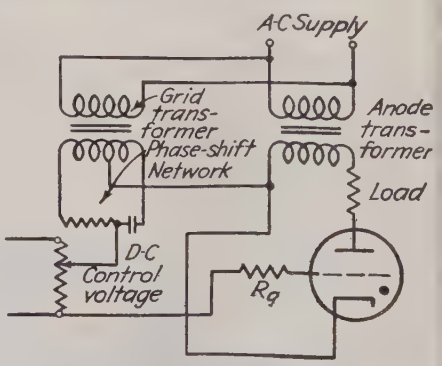


FIG. 40.—Thyratron controlled by fixed grid-voltage phase shift and adjustable d-c grid voltage.

resistance of the resistance arm of the bridge and makes the grid voltage of the thyratron less lagging with respect to the anode voltage of the thyratron. The average current of the thyratron is thus increased.

A phase-shift control circuit employing a synchro for obtaining the phase shift of the grid voltage is shown in Fig. 39. If a synchro is energized from a three-phase supply, the phase relationship of the voltage induced in any one winding on the other element may be controlled by the setting of the position of the rotor of the synchro. Any phase relationship from in phase to 180 degrees out of phase and back to in phase may be obtained.

Phase-shift control can also be obtained by means of an adjustable d-c grid-control voltage combined with an a-c voltage having a fixed phase shift. A circuit for this type of control is shown in Fig. 40. The phase-shift bridge supplying the a-c grid voltage usually is designed to make the a-c grid voltage lag the anode voltage by 90 degrees. When the d-c grid-control voltage is zero, the tube will fire slightly before the anode voltage reaches its maximum positive value, as shown in part I of Fig. 41. When a positive d-c grid-control voltage is applied, the instant of breakdown of the tube will occur earlier in the positive half cycle of the anode voltage, as shown in part II of Fig. 41. With positive d-c grid-control voltage, the conduction period can be gradually adjusted from one-half of the positive half cycle to nearly the complete positive half cycle. When a negative d-c grid-control voltage is applied, the instant of breakdown of the tube is retarded, as shown in part III of Fig. 41. With negative d-c grid-control voltage, the conduction period can be gradually adjusted from one-half of the positive half cycle down to zero conduction. Thus, with this type of phase-shift control, the conduction period can be gradually adjusted from conduction throughout practically all of the positive half cycle down to zero conduction.

Another method of obtaining phase-shift control is by energizing the grid circuit by the secondaries of three transformers, as shown in Fig. 42. Transformer 1 is a peaking transformer. A peaking transformer is one designed so that its primary current will magnetize the core to saturation throughout the major portion of time. The relations of impressed voltage, primary current, and flux are shown in Fig. 43. With such a transformer, there will be no change in the flux of the transformer except for the short intervals when the current and therefore the flux reverse in direction. During these short intervals, the flux will change rapidly and induce a sharp peak of voltage in the secondary winding, as shown in Fig. 43. The voltage relations of the grid circuit for phase-shift control employing a peaking transformer are shown in Fig. 42. Transformer 3 is connected so that its secondary voltage in the grid circuit is 180 degrees out of phase with the anode voltage. Its voltage is of sufficient magnitude to prevent the peaked voltage of the peaking transformer from firing the thyratron. Transformer 2 is connected so that its secondary voltage

in the grid circuit is in phase with the anode voltage. When the circuit of transformer 2 is closed, the in-phase voltage of its secondary will raise the peaks of voltage to a value sufficient to fire the thyratron. The

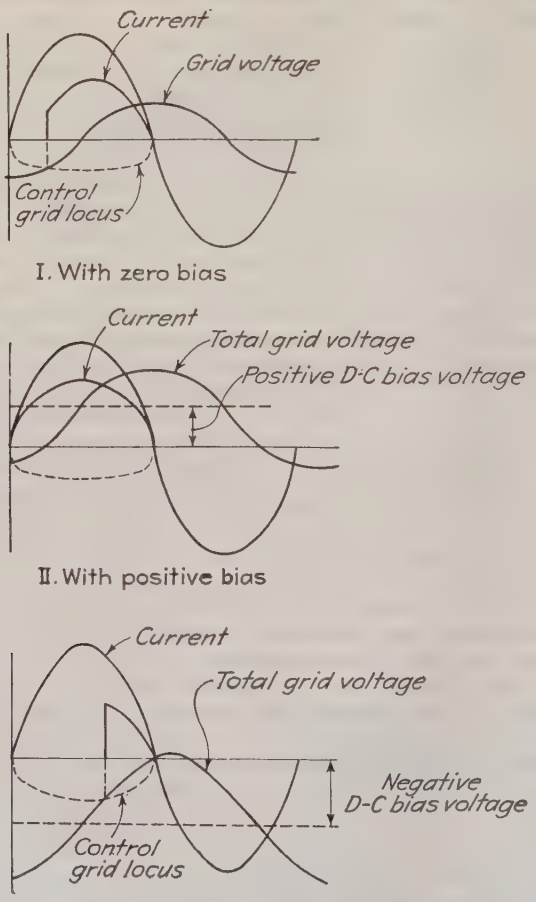
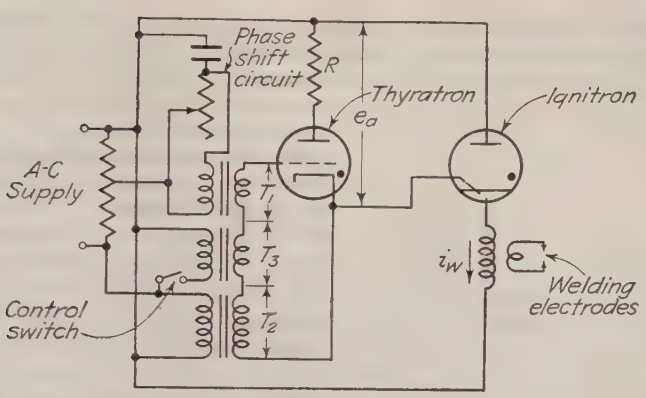
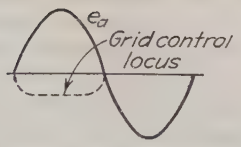


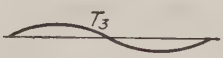
FIG. 41.—Wave diagrams showing thyratron control with fixed phase shift and adjustable bias.

thyratron must be a positive-grid-controlled tube. The location of the peaks of voltage with respect to the cycle of anode voltage can be controlled through the phase-shift bridge, which supplies the primary of the

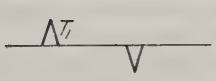




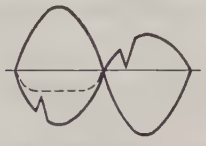
I. Supply voltage and grid control locus



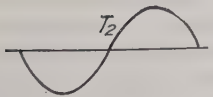
IV. In-phase grid voltage



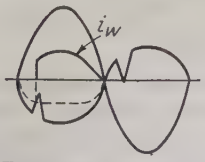
II. Peaking voltage



V. Total grid voltage when control switch is open



III. Out-of-phase grid voltage



VI. Total grid voltage and welding current when control switch is closed

FIG. 42.—Control of welding circuit with a peaking transformer.

peaking transformer. Thus the conduction period of the thyratron can be gradually controlled through the location of the voltage peaks from zero to conduction throughout practically all of the positive half cycle of anode voltage.

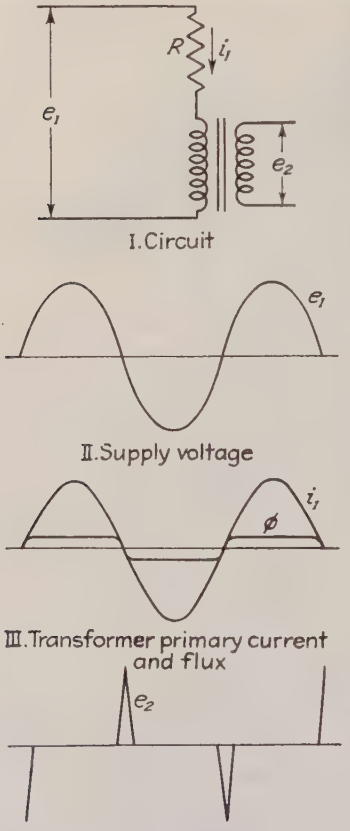


FIG. 43.—Generation of a peaking voltage pip with a saturated-core transformer.

34. The tetrode thermionic gas-filled tube is generally called a **shield-grid thyratron.** It is similar in construction to the triode gas-filled tube with the addition of a second grid called the shield grid. The shield grid consists of a metallic envelope surrounding the cathode except for a hole at the top of the shield. This hole in the shield grid is in line with the control grid and the anode. The shield grid usually is held at cathode potential and serves to conserve the heat of the cathode, to shield the cathode from stray charges on the walls of the tube, to protect the control grid from contamination by active material evaporated from the cathode, and to protect the control grid from radiant heat radiated from the cathode. The general characteristics, operation, and control of the shield-grid thyratron are the same as for the triode thyratron.

35. Phanotron and thyratron tubes are rated in cathode voltage and current, average value of plate current, peak value of plate current, peak forward voltage, and peak inverse voltage. The cathode voltage and current must be such that they are readily obtainable from the filament transformer. The cathode voltage should be maintained within ± 5 per cent of the rated value. Large tubes usually are used with individual filament transformers, small ones with the filaments in parallel across one transformer. The rated average value of plate current must be at least as large as the d-c output from the rectifier divided by the number of tubes in the rectifier. The rated peak value of current must be at least as great as the peak of the current output wave and must not be exceeded.

The peak forward voltage is the highest voltage at which the grid can safely maintain control of the conduction. The peak inverse voltage is the maximum negative voltage to which the plate should be subjected. The greatest value of peak inverse voltage will occur in the case of full-wave single-phase rectification. In such a circuit, the peak inverse voltage will be $2\sqrt{2}$ times the value of the a-c voltage between a line terminal and the mid-point of the plate-circuit transformer.

MERCURY-POOL TUBES

36. Diode mercury-pool tubes are probably the oldest form of electron tube. They have been known for years as **mercury-arc rectifiers.** The mercury-arc rectifier consists of an enclosing envelope of glass or metal containing a pool of mercury at the bottom of the chamber. The mercury pool forms the cathode of the tube. One or more anodes made of iron or graphite are supported by the enclosing structure at a proper distance above the surface of the pool. The present-day use of the mercury-arc rectifier tubes is principally in the larger sizes, which use a steel tank for the enclosure. A cross section of one of these large mercury-arc rectifiers is shown in Fig. 44. The low pressure required in the tube is maintained by means of a motor-driven vacuum pump. In order to start the rectifier, an auxiliary anode is required for striking an arc and producing mercury vapor from the surface of the mercury pool. In Fig. 44, the starting anode S is raised or lowered by means of a solenoid. In starting the rectifier, the starting anode is lowered into the mercury pool and then withdrawn. As the starting anode is withdrawn from the mercury pool, an arc is formed which ionizes the mercury and fills the tube with ionized mercury vapor. Gaseous conduction will then take place from the mercury pool to the main anode or anodes. Conduction will be self-sustaining as long as the current does not drop to zero and an anode is maintained at positive potential with respect to the mercury-pool cathode. In polyphase rectifiers under normal operating conditions, conduction will shift from the anode of one phase before that anode has ceased to conduct to the anode of another phase. In this manner, the current is never allowed to drop to zero, and conduction is maintained until the circuit is broken by some switching means.

In the rectifier of Fig. 44, the solenoid, which operates the starting anode, is automatically controlled so that, if the arc is extinguished during operation because of some abnormal condition, the starting anode will automatically be lowered into the mercury pool and then withdrawn, striking an arc and restarting the rectifier. In single-phase rectifiers, an auxiliary keep-alive circuit is often provided. The keep-alive circuit requires that the tube be provided with an auxiliary set of anodes connected to a supply voltage in series with an inductance. The inductance load of the keep-alive circuit makes the current lag behind the voltage, and conduction is thereby maintained to one anode until conduction has

started to the other auxiliary anode. The keep-alive circuit maintains ionized mercury vapor in the tube so that, if current to the main anodes is interrupted, conduction to the main anodes will be automatically reestablished as soon as any main anode becomes positive with respect to the cathode. Small single-phase rectifiers are generally provided with an auxiliary starting anode mounted close to the mercury pool and con-

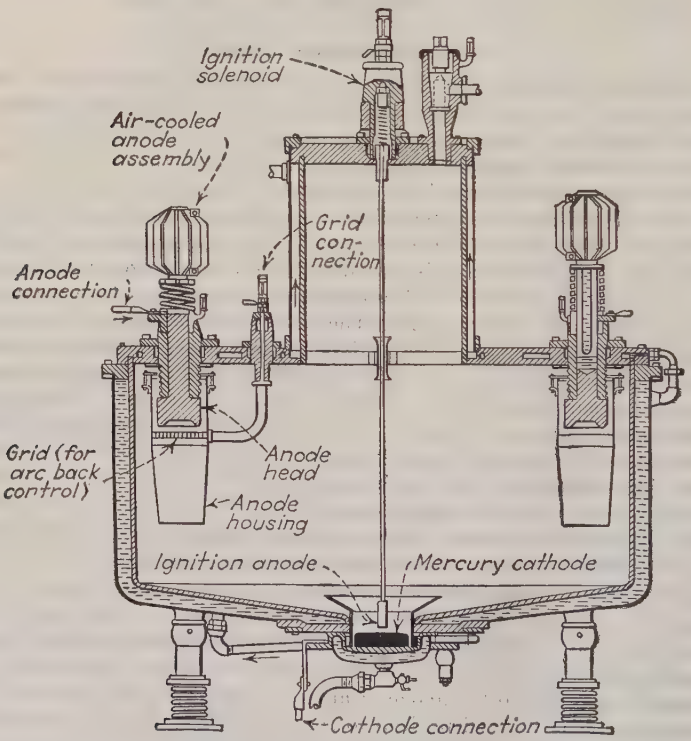


FIG. 44.—Tank-type mercury-arc rectifier.

tinuously connected to a voltage supply whenever the tube is operating. An auxiliary automatically controlled mechanism tilts the tube for starting of the rectifier. As the tube tilts, mercury bridges the gap between the mercury pool and the starting anode. As the tube comes back to normal position, an arc is formed as the mercury recedes from the starting anode, mercury vapor is formed, and the keep-alive or main anodes become conducting.

The anode current of diode mercury-pool tubes cannot be controlled by the tube. The voltage drop from cathode to anode is of relatively

low value from 12 to 30 volts. The voltage drop is practically independent of the magnitude of the anode current. Unless excessive voltage is applied to the tube, the tube will allow the passage of current in only one direction between the cathode and any one anode. These tubes therefore have rectifier characteristics.

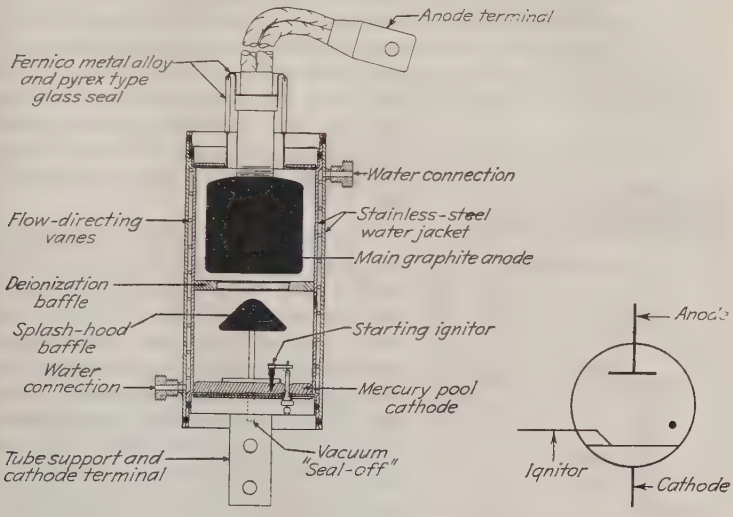


FIG. 45.—Ignitron tube. (*General Electric Co.*)

37. Triode mercury-pool tubes are known as **ignitrons.** They overcome the no-control-of-anode-current disadvantage of the diode mercury-pool rectifiers tubes. Control of the point in the positive half cycle when current starts and therefore control of the average anode current is obtained by means of a control electrode called the ignitor. The essential elements of the construction of an ignitron tube are shown in Fig. 45. The cathode of the tube is provided by a pool of mercury at the bottom of the enclosing envelope. A single anode is mounted above the mercury pool. The ignitor (the control electrode) is made of high-resistance, refractory material and has a conelike tip. The ignitor electrode is so mounted that its conelike tip is immersed in the mercury pool. Surface tension produces a very small separation between the tip of the ignitor and the mercury pool. When sufficient voltage is applied between the mercury pool and the ignitor, arcing occurs from the surface of the mercury pool across the small separation to the tip of the ignitor. This arc produces ionized mercury vapor throughout the enclosure of the tube.

Gaseous conduction will then start from the mercury pool to the anode, whenever the anode is positive with respect to the mercury-pool cathode. Conduction to the anode will continue until the voltage applied from cathode to anode drops below the voltage drop from cathode to anode. If the ignitor circuit is continually energized or is energized at the start of each positive cycle of the anode voltage, current will flow in the cathode-anode circuit during practically all of each positive half cycle. By controlling the time in the positive half cycle of anode voltage at which the ignitor circuit is energized, the portion of the positive half cycle during which anode conduction takes place can be controlled. Thus the average anode current of the ignitron tube can be controlled in a manner similar to that of a thyratron tube (see Sec. **33**).

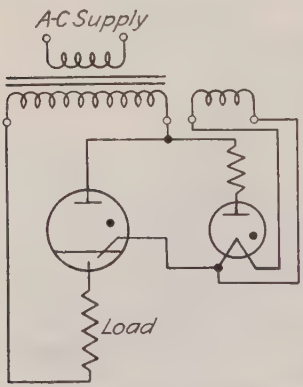


FIG. 46.—Circuit of an ignitron tube controlled by a gas-filled diode. (Load-current ignition.)

The ignitor of the ignitron tube, like the grid of the thyratron tube, has control of only the starting of conduction and has no control over the magnitude of the anode current once conduction is started and the anode is maintained positive with respect to the cathode. Like the thyratron tube, however, the ignitron tube can control the average anode current when alternating voltage is applied to the cathode-anode circuit. The characteristic of the ignitron differs from that of the thyratron, in that the ignitron will not start until forced to do so by energizing the ignitor circuit, whereas the thyratron remains nonconducting only so long as it is prevented from starting by application of the proper potential to the control grid. The voltage drop of ignitron tubes is very nearly the same as for diode-mercury-vapor tubes and is practically independent of the magnitude of the anode current. Unless excessive voltage is applied from cathode to anode, ignitron tubes will allow the passage of current in only one direction.

38. Control of Ignitron.—The ignition potential for the ignitor circuit generally is secured from a diode or triode thermionic-gas filled tube or the combined use of both of these types of tubes. When no control of the conduction period is desired, the ignitor circuit is supplied by a diode tube. When the time of the conduction period must be controlled, the ignitor circuit is supplied by a triode or a circuit employing both a diode and a triode. Two general types of ignition circuits are employed. In one type, the ignition current passes through the load of the ignitron. These ignition circuits are known as load-current ignition circuits. In

the other type, the power for ignition is obtained from a circuit separate from the load. These ignition circuits are known as separately excited ignition circuits.

A simple load-current ignition circuit employing no control of the conduction period of the ignitron and using a diode ignition tube is shown in Fig. 46. When the anode of the diode ignition tube becomes positive, current flows from the positive terminal of the supply, through the diode ignition tube to the ignitor, through the load, and back to the

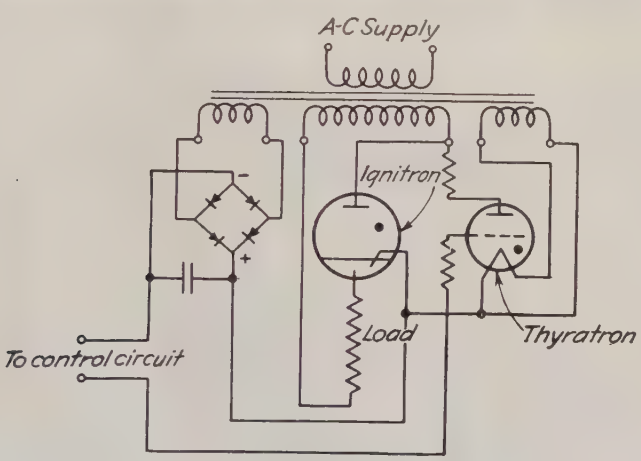


FIG. 47.—Circuit for an ignitron tube controlled by a thyratron. (Load-current ignition.)

negative terminal of the supply. The anode current of the ignitron is thus initiated, and current passes through the ignitron and load until the potential across the ignitron tube drops to the extinction point of the arc. The ignition process is repeated each positive half cycle. The ignition tube should have a higher arc drop than that of the ignitron tube so that the ignitor current will be stopped immediately after ignition of the ignitron takes place.

A load-current ignition circuit that may be used for control of the conduction time of the ignitron is shown in Fig. 47. A triode thermionic gas-filled tube is employed for the control of the ignitron. Grid-bias voltage is supplied to the control tube by means of a contact rectifier with a capacitor filter (see Sec. **49**). When the control tube breaks down, current passes from the positive terminal of the supply through the control tube to the ignitor, through the load, and back to the negative terminal of the supply. As in the circuit of Fig. 46, the control tube should have a higher arc drop than that of the ignitron. Control of the conduction time of the ignitron is obtained by controlling the point in the

positive half cycle at which the control tube breaks down. Any of the methods described in Sec. **33** may be employed for this breakdown control.

A separately excited ignition circuit is shown in Fig. 48. This circuit employs two control tubes, a diode and a triode. During the half cycle when the anode of the ignitron is negative, the capacitor C is charged through the transformer and diode tube T. During the half cycle when the anode of the ignitron is positive, the polarity of the charged

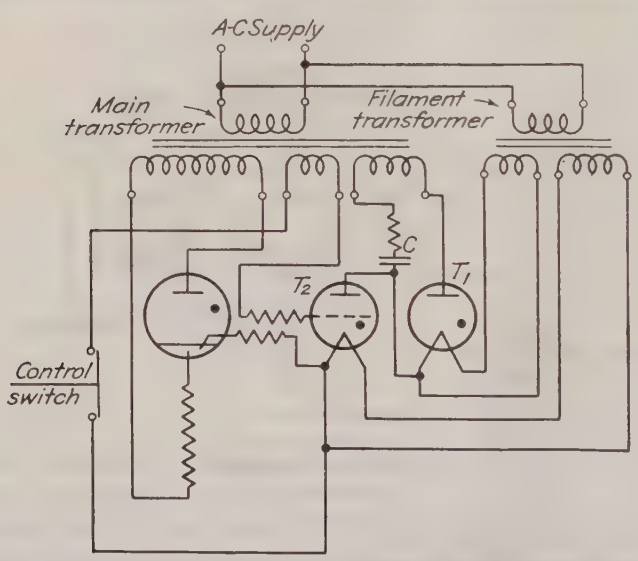


FIG. 48.—Circuit for an ignitron tube controlled by a capacitor discharge. (Separately excited ignition.)

capacitor C is such that the capacitor cannot discharge through the diode tube T_1 but it is of the polarity so that it is possible for it to discharge through the circuit formed by the thyratron T_2 and the ignitor of the ignitron. The point in the cycle when the capacitor discharges through this circuit depends upon the point at which the triode tube T_2 breaks down. The breakdown point of tube T_2 will depend upon the grid-bias voltage and the grid-control voltage used for tube T_2. In Fig. 48, tube T_2 is biased with an alternating voltage obtained from the transformer at the top of the figure. The grid-control voltage is applied across the terminals marked input and could be obtained from some form of phase-shift circuit. When tube T_2 breaks down, the capacitor discharges through tube T_2 and the ignitor and thus initiates conduction through the ignitron tube and load.

39. Mercury-pool tubes are rated in average value of anode current, peak value of anode current, peak forward voltage, and peak inverse voltage. The ratings have the same meaning as explained in Sec. **35.**

COLD-CATHODE, GAS-FILLED TUBES

40. Cold-cathode, Gas-filled Tubes.—In cold-cathode, gas-filled tubes the cathode consists of a simple solid metallic electrode, which may or may not be coated to lower the required emission energy. The tube is generally filled with some inert gas at low pressure. When sufficient voltage is applied between the two main electrodes, the gas will be ionized, and emission will be produced at one of the electrodes for maintaining the conduction. The emission of electrons from a cold cathode is a complex phenomenon and in most cases probably is a combination of all four of the causes of emission explained in Sec. **2.** The principal cause of emission in most cases undoubtedly is electric-field emission. The voltage from cathode to anode required to produce conduction with cold-cathode tubes is therefore much greater than is required with hot cathodes or mercury-pool cathodes. The amount of emission is also limited with cold-cathode tubes, and the anode current of cold-cathode tubes is therefore limited to small values. In cold-cathode tubes, the two main electrodes may have identical construction so that either electrode may function as either cathode or anode, depending upon the polarity of the impressed voltage. A tube with this construction will pass current in either direction and will not have rectifying characteristics. If the two main electrodes have different construction, so that it is much more difficult to produce emission from one of the electrodes than from the other, then only one of the electrodes will function as an emitter unless excessive voltage is applied to the tube. Tubes with this electrode construction, under normal operating conditions, will pass current in only one direction and will, therefore, possess rectifying characteristics. Cold-cathode tubes require appreciably more voltage to break down the gas and start conduction than is required to maintain conduction after it has been started. The cathode-anode voltage drop during conduction depends upon the type of gas and pressure employed in the tube and in some cases upon the temperature of the gas. The voltage drop is practically independent of the magnitude of the current. It is always necessary to have an impedance connected in series with the anode circuit in order to control the magnitude of the anode current and to

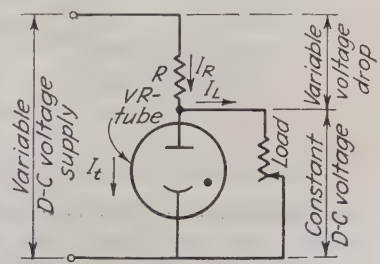


FIG. 49.—Voltage-regulating circuit employing a VR tube.

limit the current to a safe value. The voltage drop will be much greater in the cold-cathode tube than in hot-cathode or mercury-pool-cathode tubes.

Diode tubes of the cold-cathode type are used as voltage-regulating devices in many electronic circuits for the purpose of providing a practically constant voltage source. When the tube is connected in series with a resistance to a source of voltage, a practically constant voltage may be obtained across the tube for the operation of some other circuit, as shown in Fig. 49.

Triode tubes of the cold-cathode type are used for control purposes in low-current applications where the cathode-heating power required for hot-cathode tubes would be detrimental or inconvenient. The control grid of a triode, cold-cathode tube will function in the same manner as the control grid in a triode, hot-cathode tube (the thyratron). The control grid of the cold-cathode tube will, therefore, have the ability to control the start of anode current but will have no control over the magnitude of the anode current once conduction has been started.

CATHODE-RAY TUBES

41. The cathode-ray tube is a special type of thermionic tube which produces a beam of electrons directed against a luminescent screen or target. It employs a glass envelope which usually is highly evacuated. Certain types of these tubes contain an inert gas at low pressure. The

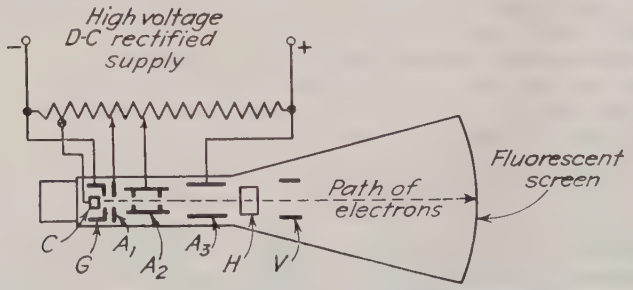


FIG. 50.—Arrangement of electrodes in a cathode-ray tube.

essential construction, functioning, and operation of a cathode-ray tube may be understood by study of Fig. 50. The construction consists of an indirectly heated cathode C; a control grid G for controlling the number of electrons in the beam; an anode A_1 to accelerate the electrons; an anode A_2 to focus the beam of electrons and further accelerate them; a high-voltage anode A_3 for further acceleration of the electrons; two sets of deflecting plates H and V for deflection of the beam in horizontal and vertical directions, respectively; and a luminescent screen consisting of a luminescent coating on the inner surface of the bulb. A certain number

of the electrons emitted by the cathode, as controlled by the grid G, are highly accelerated and directed in a narrow beam by means of the small apertures in grid G and anodes A_1 and A_2 toward the screen. When no voltage is applied to either of the sets of deflecting plates H and V, the beam of electrons, when properly adjusted, will strike the screen at its center point and produce a luminous spot at that point. The direction of the beam and consequently the location of the luminous spot produced on the screen can be controlled by the application of voltages between the horizontal plates and between the vertical plates.

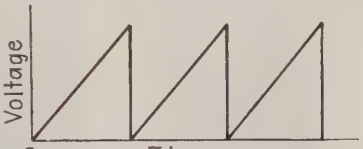


FIG. 51.—Linear sweep voltage.

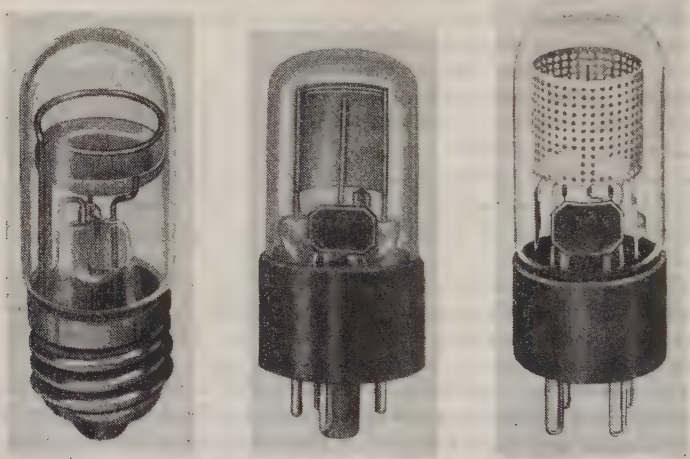
The cathode-ray tube, when combined with power supply and control circuits to form the instrument known as a cathode-ray oscilloscope, is a versatile measuring and testing instrument. The practical applications of the cathode-ray oscilloscope are growing continually.

The cathode-ray oscilloscope is provided with a control circuit, which will impress a voltage between the horizontal deflecting plates that will vary directly with respect to time. The wave form of such a voltage is shown in Fig. 51. The circuit is so constructed and controlled that this voltage between the horizontal plates will cause the spot on the screen to sweep across the screen horizontally at a uniform velocity. For this reason such control circuits are called sweep circuits. With the sweep circuit operating, if a varying voltage is applied between the vertical deflecting plates V, the spot will trace a luminous pattern on the screen. By proper adjustment of the frequency of the sweep circuit, a periodically varying voltage impressed on the vertical plates will produce a trace on the screen that will appear stationary and will show the wave form of the voltage.

PHOTOTUBES

42. Phototubes are photoemissive electron tubes. All phototubes are constructed as diodes. The cathode generally is constructed of sheet metal bent into semicircular form so as to give appreciable exposure to the incident light (see Fig. 52). The inner surface of the cathode is coated with a light-sensitive emitting material (see Sec. **11**). The anode consists of a wire located approximately along the axis of the cathode. When light falls upon the coated cathode, electrons are emitted. The amount of emission will depend upon the wave length of the incident light, the material of the coating, and the amount of light falling upon the coating. When the anode is made positive with respect to the cathode and incident light is producing emission, conduction will take place from

cathode to anode. Conduction in phototubes depends upon the anode being positive, and they therefore possess rectifying characteristics. Phototubes are made in both vacuum and gas-filled types.



I. End-type cathode II. Semi cylindrical cathode III. Perforated cylindrical cathode

FIG. 52.—Phototubes showing different types of cathode constructions. (*RCA Manufacturing Co.*)

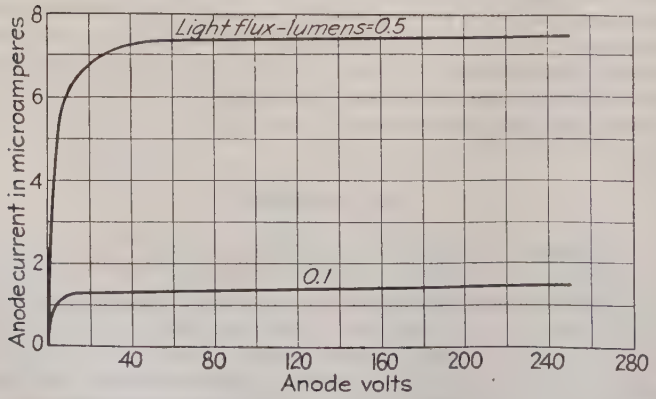


FIG. 53.—Plate current–voltage characteristic curves of a vacuum phototube (RCA type 925). (*RCA Manufacturing Co.*)

In the vacuum type of phototube, the anode current for a given illumination of the cathode rises rapidly with increasing anode voltage until the electrons are pulled across to the anode as fast as they are

emitted. Any further increase in the anode voltage produces little effect upon the anode current. Typical anode-current versus anode-voltage characteristics are shown in Fig. 53. Provided that the tube is operated with an anode voltage above the saturation point, the anode current is practically proportional to the amount of light falling on the coated cathode. Typical anode-current versus incident-light-flux characteristics are shown in Fig. 54.

In the gas-filled type of phototube, the anode current for a given illumination of the cathode increases continually as the anode voltage is

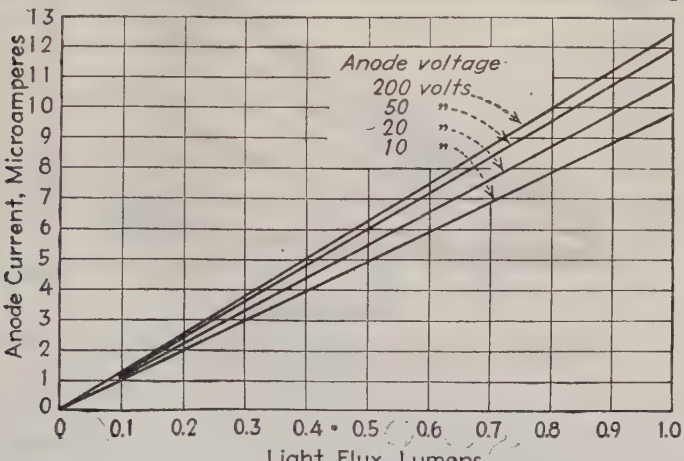


FIG. 54.—Plate current–light flux characteristic curves of a type PJ-22 vacuum phototube. (*General Electric Co.*)

increased. For low voltages, the current rises rapidly until the electrons are pulled across to the anode nearly as fast as they are emitted. Further increase in voltage at first increases the anode current only slightly. Up to this point on the characteristic the gas has not been materially ionized. As the voltage is still further increased, the gas is ionized, and the current increases rapidly with increase in voltage. Typical anode-current versus anode-voltage characteristics are shown in Fig. 55. For a definite anode voltage, the anode current increases with the amount of light falling upon the cathode, but the current is not proportional to the amount of incident light. Typical anode-current versus incident-light-flux characteristics are shown in Fig. 56.

Phototube circuits in themselves are very simple. They consist of a d-c supply voltage connected in series with the tube and the load element, as shown in Fig. 57.

43. Photoconductive cells are photosensitive devices. They are not phototubes, and, although they generally are classed as such, they

are not strictly electronic devices. Although they may be enclosed in an evacuated space, their functioning does not depend upon conduction

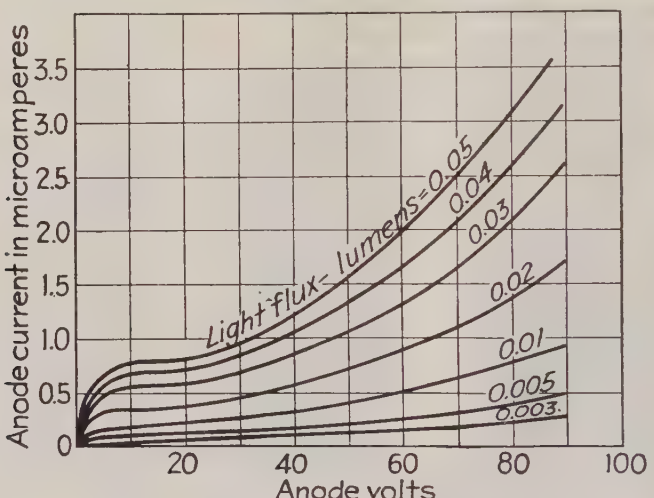


FIG. 55.—Plate current–voltage characteristic curves of a gas-filled phototube (RCA type 920). (*RCA Manufacturing Co.*)

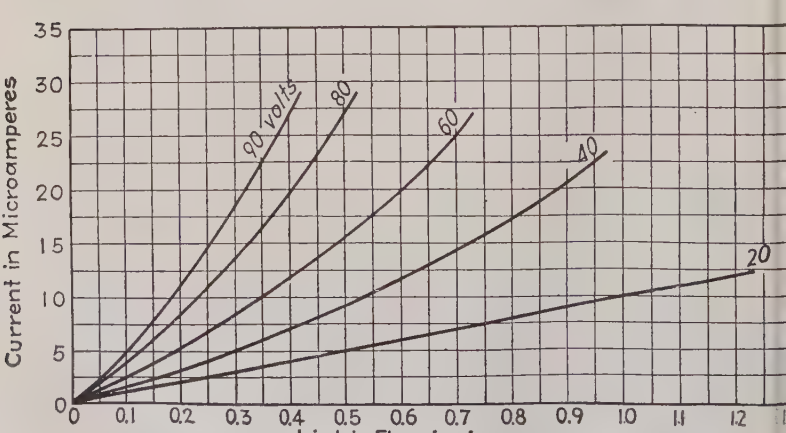


FIG. 56.—Plate current–light flux characteristic curves of a type WL735 gas-filled phototube. (*Westinghouse Electric Co.*)

in a vacuum or in a gas. Photoconductive cells function through the effect of light upon the electrical resistance of certain materials. Some 15 or more natural minerals have been found that possess this photo-

conductive property. Selenium however, is the only material possessing this characteristic that has been used to an appreciable extent for the construction of photoconductive cells. Typical construction of a selenium cell is shown in Fig. 58. A thin layer of platinum or gold is supported between two glass plates. A thin line is scratched through this conducting layer of platinum or gold, and the line is filled with selenium. The electric path through the cell is from terminal 1 through side *A* of the layer of platinum or gold to the line of selenium, through the selenium to the side *B* of the platinum or gold, and through side *B* of the layer of platinum or gold to terminal 2.

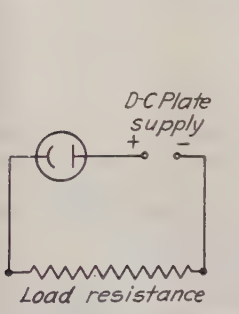


FIG. 57.—Fundamental phototube circuit.

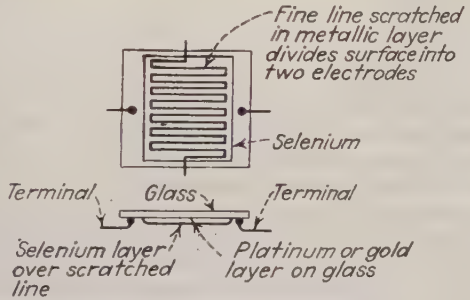


FIG. 58.—Selenium photoconductive cell.

Selenium is a semiconductor, *i.e.*, neither a good conductor nor a good insulator. When it is illuminated, its resistance decreases so that it becomes a better conductor. Thus, in the selenium cell, as the light falling on the cell increases, the resistance from terminal 1 to terminal 2 decreases, and the current through the cell for a definite impressed voltage will increase. The increase in current caused by illumination is not directly proportional to the increase in light falling on the cell. Selenium cells have only a very limited field of application.

44. Photovoltaic cells are photosensitive devices but, like photoconductive cells, are not phototubes nor are they strictly electronic devices. Photovoltaic cells function by virtue of the ability of certain types of barrier layers between two substances to produce an e.m.f. from one of the substances to the other when the barrier layer is illuminated. Two barrier layers that have been used in commercial photovoltaic cells are cuprous oxide and selenium. When the barrier layer is illuminated, a small voltage is produced between the two terminals of the cell. The magnitude of the voltage produced will increase with the amount of illumination of the sensitive barrier layer. A cuprous oxide cell is manufactured by the Westinghouse Electric & Manufacturing Co. and is known as the photox cell. It consists of a layer of cuprous oxide

between a copper disk and a thin transparent metallic film. A commercial selenium cell is the Weston photronic cell. It consists of a thin layer of selenium on an iron disk. Photovoltaic cells are used widely for illumination measurements.

FUNCTIONS OF ELECTRON TUBES

45. Functions of Electron Tubes.—The principal functions that electron tubes are capable of performing are

1. Rectification.
2. Amplification.
3. Relay.
4. Switch.
5. Oscillator.
6. Modulation.
7. Detection.

46. Electron Tubes as Rectifiers.—As discussed in Sec. **8,** most electron tubes possess a rectifying characteristic, allowing, unless excessive voltage is applied, the passage of current through the tube in only one direction. The purpose of using the tube may not be to perform this rectifying function. The tube is called a rectifier only when it is used primarily to perform the function of rectification. Tubes are used extensively as rectifiers for the production of direct current from an a-c supply. They are applicable over the complete rectification field, from applications requiring the rectification of only very small amounts of power to those requiring the conversion of the largest amounts of power. Vacuum tubes are employed for rectification of power at high voltages and of low current values. Thermionic gas-filled tubes are used in low- and medium-voltage circuits having current capacities up to about 100 amp. Mercury-pool gas-filled tubes are used in low- and medium-voltage circuits requiring medium and high current capacities. Diode tubes are used for applications where it is not necessary for the tube to control the initiating of the current or the average value of the current. Triode tubes are employed where it is advantageous to have either the initiating of the current or the average value of the current controlled by the tube. Electronic rectifiers may be used for supplying direct current from either single-phase or polyphase sources.

47. Diode Rectifier Circuits.—The simplest electronic rectifier circuit is the single-phase half-wave rectifier shown in Fig. 59. In this type of rectifier, the a-c power supply has a high ratio of peak load to average load, since it is delivering power only half the time. The single-phase full-wave rectifier circuit, shown in Fig. 60, overcomes this difficulty. During one half cycle the current path is from the transformer to the anode of the upper tube in the figure, through the tube to the load, and back to the center point of the transformer. During the other half of the cycle, the current passes from the transformer to the anode of the lower

tube, through the tube to the load, and back to the center point of the transformer. With this circuit, each half of the transformer winding is used only half of the time. Another type of full-wave rectifier circuit is known as the bridge type of rectifier. It employs four tubes connected as

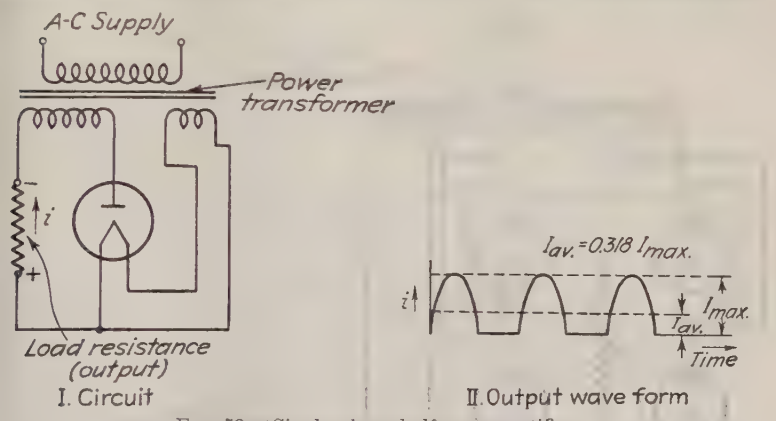


FIG. 59.—Single-phase half-wave rectifier.

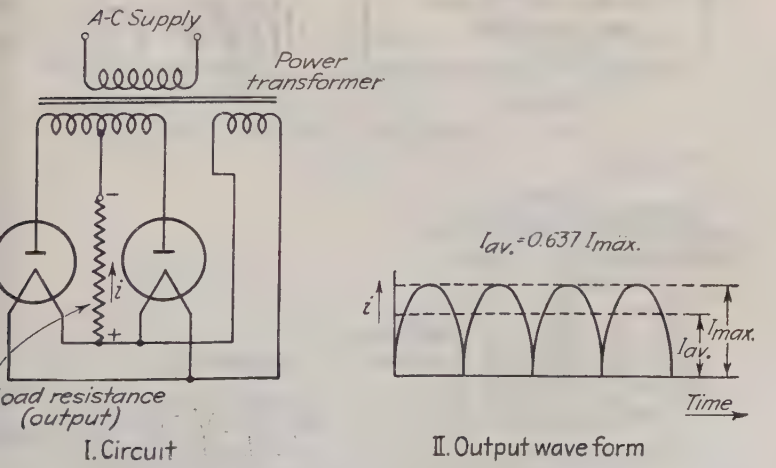


FIG. 60.—Single-phase full-wave rectifier.

shown in Fig. 61. The bridge rectifier circuit utilizes all of the transformer winding continuously and gives a low ratio of peak power to average power. On the other hand, the bridge rectifier requires four tubes against two for the other type of full-wave rectifier.

Some diode tubes of the thermionic vacuum, thermionic gas-filled, and

mercury-pool tubes are made with two anodes and a common cathode in the same enclosing envelope. These tubes are used for single-phase full-wave rectification and are connected as shown in Fig. 62. Applications of such tubes are shown in the circuits of Figs. 66 to 70.

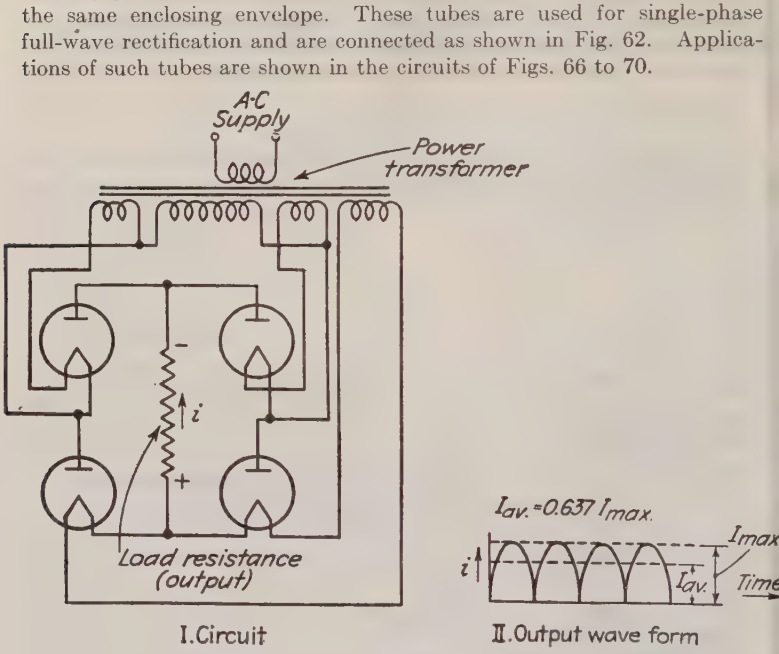


FIG. 61.—Single-phase bridge-type rectifier.

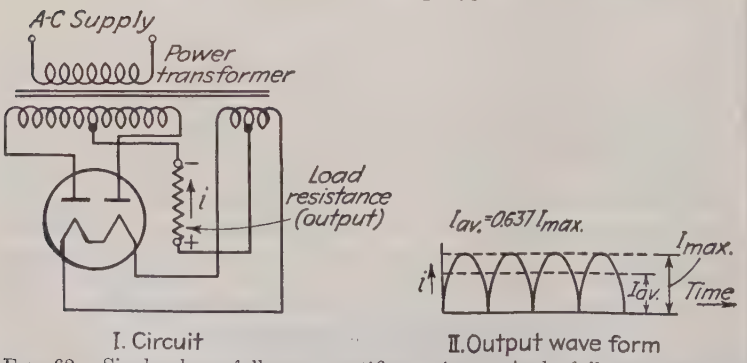


FIG. 62.—Single-phase full-wave rectifier, using a single full-wave rectifier tube.

For large amounts of power, the rectifier supply is generally taken from all three phases of a three-phase source. Three-phase rectifier circuits are shown in Figs. 63 to 65.

48. Triode Rectifier Circuits.—In the diode rectifier circuits of Sec. **47**, the amount of power delivered to a given load depends entirely on the supply voltage. Also the initiating of current depends entirely on the closure of the power supply and load circuits. Often it is advantageous to have either or both the initiation of current and the amount of power

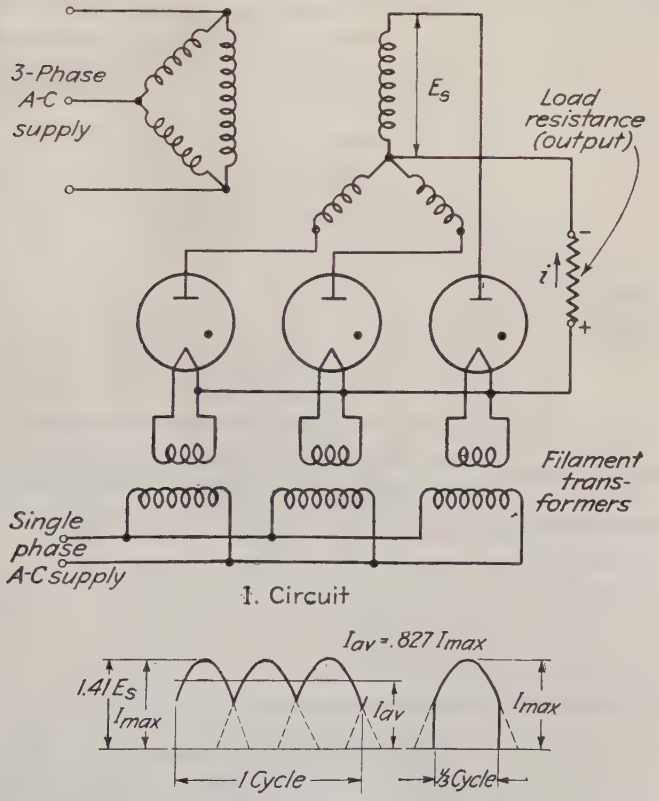


FIG. 63.—Three-phase half-wave three-tube rectifier.

ontrolled by other means. This control is possible through the use of iode tubes and the control of the anode current by means of the control id. Triode rectifiers are called controlled rectifiers. Vacuum tubes an be employed for controlled rectifiers, but the greater economy arough lower voltage drop and the higher current capacities of gas-lled tubes eliminates the vacuum tubes for these applications except r high voltage or very low current applications. With the triode gas-

filled rectifiers, the amount of power delivered to the load is controlled by the portion of the time during each cycle that current is allowed to pass

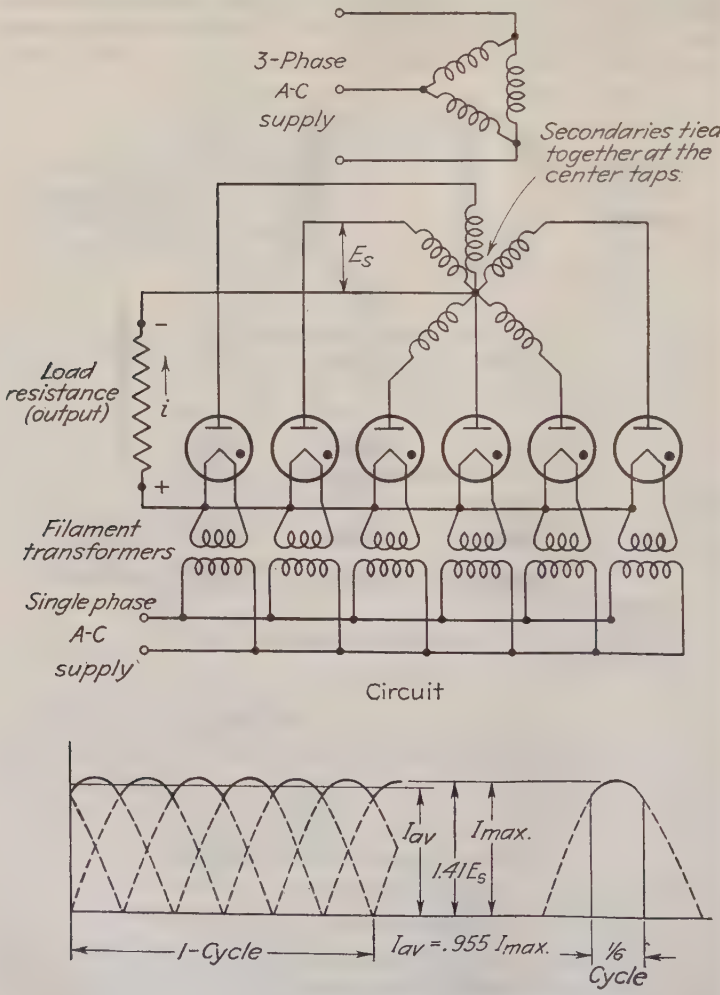


FIG. 64.—Three-phase full-wave six-tube rectifier.

through the tube to the load, as discussed in Sec. **33** for thyratron tubes and in Sec. **39** for ignitron tubes. The connections for the anode-load circuits of triode rectifiers are the same as for diodes, as given in Sec. **47.**

To the anode-load circuits of these figures must be added the grid-control circuit for each tube. The fundamentals of these grid-control circuits are given in Secs. **33** and **38**.

49. Filters.—The d-c output voltage and current of all the rectifier circuits discussed in Secs. **47** and **48** will not be of constant magnitude but will vary considerably. It is seen that the variation of the d-c output voltage is greatest for the half-wave single-phase rectifiers,

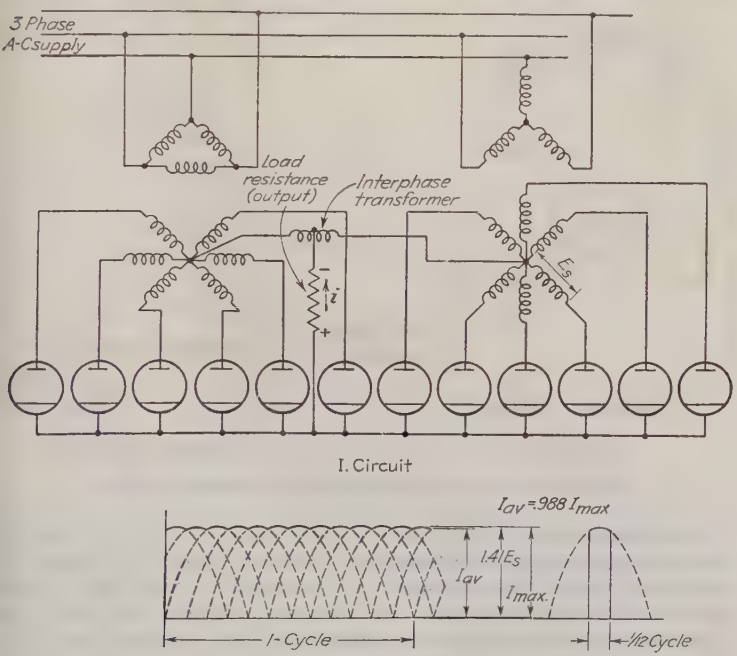


FIG. 65.—Three-phase 12-tube rectifier.

nd that the amount of variation is decreased as the number of phases is ncreased. The variation in the output voltage is called a ripple. If the ectifier is supplying power to an inductive load, the inductance of the oad will reduce the amount of ripple present in the current. In many ases, especially with single-phase rectifiers, a more constant d-c output oltage is required than can be obtained from the basic rectifier circuit. n order to produce this reduction of the ripples in the rectifier output nd make the load current more constant, additional circuit elements re inserted between the output terminals of the rectifier and the load. he combinations of circuit elements employed for this purpose are called

filters. They filter out the ripple in the d-c output delivered to the load so that the voltage and current of the load are more nearly of constant magnitude. It is not possible to eliminate the variations completely, and the degree to which the ripple is removed depends upon the complexity of the filter circuit employed.

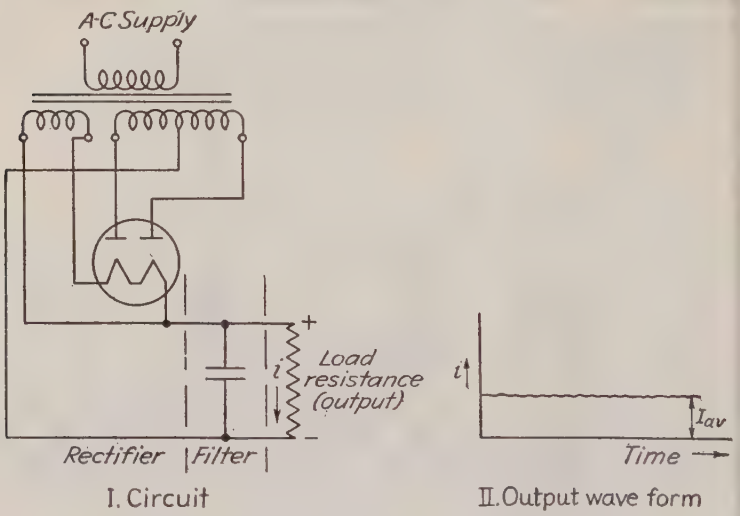


FIG. 66.—Full-wave rectifier tube with capacitor filter.

The simplest form of filter for a rectifier consists of either a capacitor connected across the output terminals of the rectifier or of an inductance connected in series with the output of the rectifier. Such simple filters are shown in Figs. 66 and 67. The capacitor will offer relatively small opposition to the passage of current produced by the ripple components of the voltage but will offer practically infinite opposition to the passage of current produced by the constant portion of the voltage. The variations in the rectifier output voltage will therefore produce an alternating current through the capacitor, and this alternating current, in passing through the rectifier and its supply, will produce an alternating voltage drop. The capacitor does not cause any d-c component of current to flow through the rectifier, and there is therefore no d-c voltage drop in the rectifier because of the filtering capacitor. Thus some of the ripple voltage of the rectifier is consumed in the rectifier itself because of the alternating current drawn from it by the filtering capacitor. The voltage at the output terminals of the filtering capacitor therefore does not contain as much ripple as would be present without the filtering capacitor. The capacitor also helps to remove the ripple through an

additional smoothing action. Since all the ripple cannot be removed by the previously explained filtering action, the output voltage will contain some ripple. Therefore, the output current will not be constant. As the output current tends to drop because of drop in the output voltage, the capacitor will discharge to the load, helping the rectifier to supply the load current. This relief of some of the load from the rectifier will tend to keep its output voltage from dropping. As the output current tends to rise because of rise in output voltage, the capacitor at the same time will be charging and pulling additional current through the rectifier.

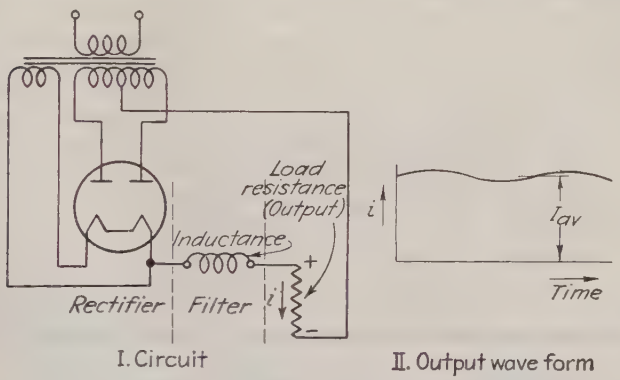


FIG. 67.—Full-wave rectifier with inductance filter.

This additional current caused by the capacitor, as the voltage tends to rise, will produce greater voltage drop in the rectifier and thereby tend to keep the output voltage of the rectifier and capacitor filter from rising. The capacitor filter will also tend to hold the current through the rectifier more nearly constant as load changes and thereby to hold the output voltage more nearly constant with varying load conditions. The capacitor acts as a storage tank to aid the rectifier. At some instants of time, the capacitor is taking power from the rectifier, and the capacitor is being charged. At other instants of time, the capacitor is discharging to the load and aiding the rectifier to supply the power to the load.

Consider the simple inductance filter of Fig. 67. The inductance filter element will of course have some resistance in addition to its inductance. When the supply voltage to the inductance filter is varying, as it will be in a rectifier circuit, the current will vary. The d-c component of the current supplied by the rectifier will produce a voltage drop in the filter element of a magnitude depending only on the resistance of the filter. The a-c, or ripple, component of the current will produce a voltage drop in the filter element depending upon both the resistance and the inductive reactance of the filter. Since the filter is designed so that its reactance is much greater than its resistance, the alternating voltage drop in the

filter will be much greater than the direct voltage drop. A large portion of the ripple voltage will be consumed as voltage drop in the filter, and the voltage at the output terminals of the filter will be more constant than the output voltage of the rectifier.

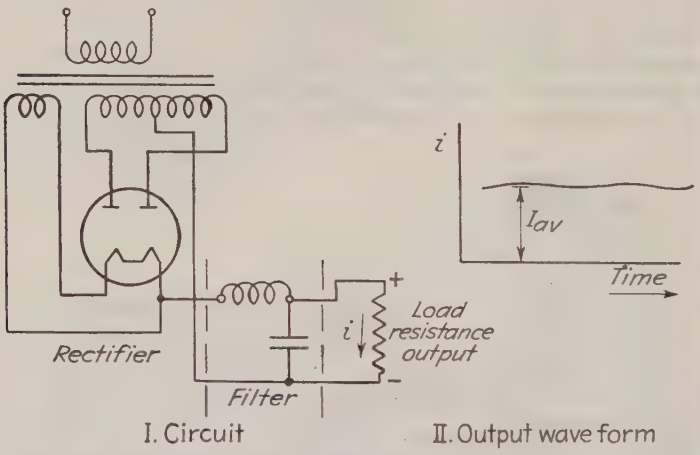


FIG. 68.—Full-wave rectifier with inverted-L inductive input filter.

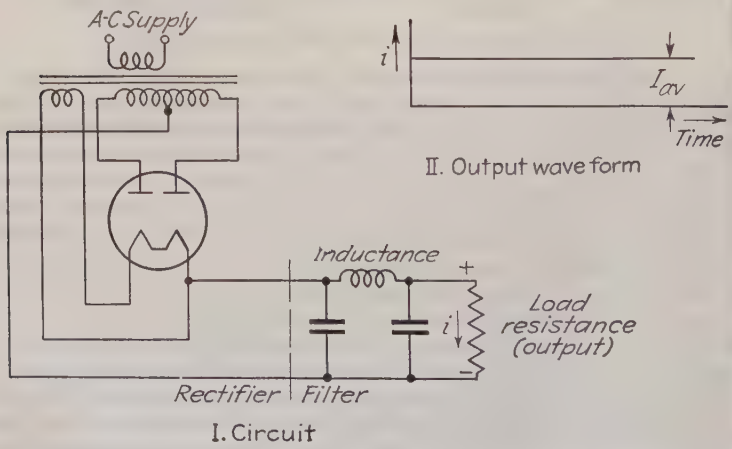


FIG. 69.—Full-wave rectifier tube with pi capacitive input filter.

Better filtering action of the supply voltage than can be obtained by either the simple capacitor or the inductance filter can be secured by proper combinations of parallel capacitors and series inductances. Common combinations employed for power-supply filters are shown in Figs. 68

and 69. As many sections of L or pi filters connected in series may be employed as are warranted by the degree of smoothness required in the wave form of the output voltage. In some cases where only moderate filtering is required, a pi type of filter using resistance instead of inductance is employed. Such a filter will not produce as good smoothing action of the voltage wave form but will cost less than one employing inductance.

Capacitors are used as filtering devices in many electronic circuits for purposes other than that of removing the ripple in a rectified supply voltage. The other principal filtering applications are as **by-passing** and **blocking capacitors.** One application of a by-pass capacitor is to eliminate as far as possible the variation in a supply voltage caused by a varying load. A capacitor connected across a supply, as previously discussed, will tend to charge and discharge as the load varies. The capacitor acts as a storage tank to hold the current drawn from the supply more nearly constant and thereby to keep the voltage output of the supply more nearly constant. The capacitor across the supply may be considered as a by-pass around the supply for varying components of current. Another application of capacitors as a by-pass is for the by-passing of a-c components or variations of the current around some particular part of a circuit. If a capacitor is connected in parallel with a particular portion of a circuit, the capacitor will offer a path of low impedance to alternating or varying components of the current but will offer practically infinite opposition to the direct component of the current. Such a by-passing capacitor will, therefore, result in practically all of the direct component of the current passing through the original part of the circuit and in practically all of the alternating or varying components passing through the by-passing capacitor. The current through the original part of the circuit will be practically constant in magnitude irrespective of the variations in the current in the other parts of the circuit. A by-pass capacitor is sometimes called a **decoupling capacitor,** since it tends to prevent the passing on of the variations in certain parts of a circuit to other parts.

Blocking capacitors are capacitors that are used for the purpose of blocking the passage of direct components of current. A capacitor in any path of a circuit will offer practically infinite opposition to the passage of direct current through that path but will offer little opposition to the passage of alternating current. Thus a capacitor will block the passage of direct current through any path in series with the capacitor. Blocking capacitors are used principally when it is desired to have the variations of the circuit passed on or coupled to another circuit and where it is also necessary to prevent the passing on of the direct component of current in the first circuit to the second, or coupled, circuit. Blocking capacitors are sometimes called coupling capacitors. Refer to Sec. **53** for an application of a blocking, or coupling, capacitor.

50. Voltage Dividers.—The power supply for many electronic circuits requires several voltages. If the demands of the different parts require voltages or currents of widely different magnitudes, it may be necessary or best to provide separate supplies for each part. Often, however, different parts of the circuit require voltages of somewhat different magnitude, and the current demands are either small or of magnitudes that do not differ from each other too widely. These requirements are generally best fulfilled by means of a voltage divider supplied from one common voltage source. A voltage divider consists of series resistances or a single tapped resistor connected to a source of voltage. By the proper design of these resistors, the required fraction of the total source voltage can be obtained for the different parts of the circuit. When the current requirements are intermittent or varying, a by-pass capacitor is connected across the part of the divider so affected, in order, as explained in Sec. **49**, to hold the voltage more constant. Where the voltage must be held more nearly constant than can be obtained with this arrangement, the practically constant voltage characteristic of diode gas-filled tubes is employed for maintaining constant voltage. Such a diode will hold the voltage across a section at practically constant value. Refer to Sec. **40**.

51. Power Supplies for Electronic Circuits.—Several different supply voltages are necessary for the operation of most electronic circuits. For example, the operation of a pentode tube requires one supply voltage for the cathode-anode circuit, another for the heating of the cathode, another for the bias of the control grid, and still another for the screen-grid circuit. When the circuit employs several tubes, the number of required supply voltages may be still further increased, even though a common supply voltage may be used for some of the circuits. Some of the supply voltages required may need to be alternating, and others may need to be direct. Alternating voltage is employed, generally, for the heater circuits of indirectly heated thermionic cathodes. In a tube employed for rectification, the cathode-anode voltage supply is of course always alternating. The grid and anode voltages, in probably the majority of cases, need to be direct voltages. In many of the fundamental electronic circuits so far shown, batteries have been indicated as the source of direct voltage. This was done because the purpose of the figures was to show fundamental principles, and it was desired to keep the figures as simple and clear as possible. Although batteries are used in some special cases, they would be too expensive in first cost and renewal and too bulky to be satisfactory for use in most industrial electronic circuits. The necessary direct voltages, therefore, are usually obtained from an a-c source through the proper combination of transformers, tubes acting as rectifiers, filters, and voltage dividers. Contact rectifiers are sometimes used as the rectifying device in place of a rectifying tube. The grid-bias voltage for vacuum thermionic tubes is obtained generally from a grid-bias resistor, as explained in Sec. **18**. The funda-

mental principles and connections of power supplies for electronic circuits can be studied in Fig. 70, which shows the power supply for a two-stage amplifier.

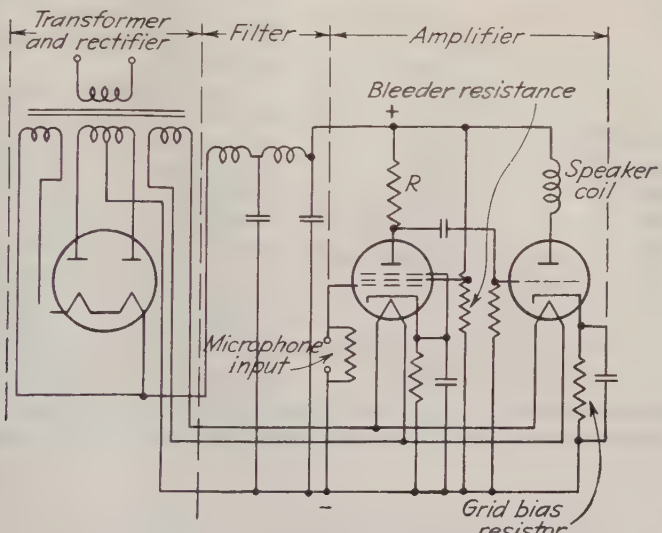


FIG. 70.—Filtered power supply connected to a two-stage audio amplifier.

52. Electron Tubes as Amplifiers.—One of the functions for which vacuum thermionic tubes are so useful is that of amplification. Amplification is the process of taking a relatively weak voltage impulse or signal and having it produce or control another voltage of much greater magnitude or power output ability. The controlled voltage or power should vary either directly or approximately directly with the signal voltage. The effect of the signal voltage is increased or amplified. A device that performs the function of amplification is called an amplifier. Because of the ability of small voltages in the control-grid circuit of vacuum thermionic tubes to produce much greater changes of voltage in the anode circuit, vacuum thermionic tubes having one or more grids are widely used as amplifiers to amplify the effect of weak potentials. By this means a very weak voltage impulse can produce much larger voltage changes in a circuit capable of delivering considerable power. If the purpose of the amplifier is simply to amplify the voltage, it is called a voltage amplifier. If the purpose of the amplifier is to produce a voltage with much greater power ability, it is called a power amplifier. The initiating voltage impulse is commonly called the signal. In addition to their extended use in radio and other communication circuits, electron-tube amplifiers are used in numerous industrial applications. True

amplifier action can be obtained only with vacuum tubes. With triode gas-filled tubes, small signal voltages may be used to initiate or control large amounts of power, but this action is really relay or switch action and not strictly amplification.

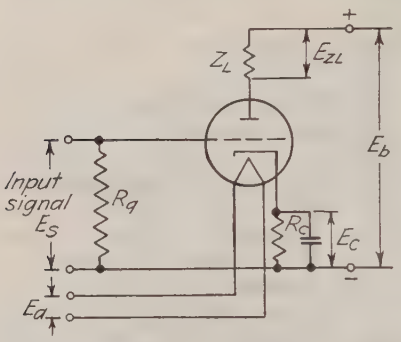


FIG. 71.—Single-stage amplifier showing voltages involved.

The fundamental amplifier action of a vacuum tube may be explained with the aid of Figs. 71 to 73. The signal voltage is impressed across the resistance R_g, which is connected in series with the bias voltage E_c in the grid-cathode circuit of the tube. When the input, or signal, voltage is zero, the anode current will be constant with a value corresponding to that given by the tube characteristic for a grid voltage of E_c. If a constant signal voltage of magnitude E_s is applied to R_g in such a

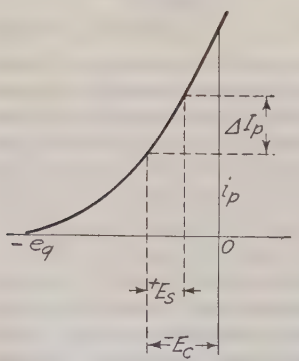


FIG. 72.—Grid voltage–plate current characteristic curve showing the effect of a positive signal voltage increasing the plate current.

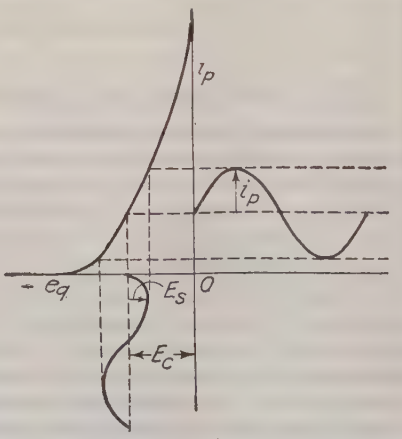


FIG. 73.—Dynamic grid voltage–plate current characteristic curves with input signal, output load, and grid-bias voltages indicated.

manner that the grid of the tube is made less negative (more positive) with respect to the cathode, the anode current will increase by the amount ΔI_p shown in Fig. 72. This increase in plate current will increase the output

voltage across the load impedance Z_L, and the increase in this output voltage will be several times the value of the input, or signal, voltage impressed in the grid circuit. If the signal voltage is an alternating voltage, the variations of the cathode-grid potential produced thereby will result in variations of the anode current, as shown in Fig. 73. These variations of the plate current will produce variations of the output voltage across the load impedance Z_L, and the variations in the output voltage will be much greater than the variations in the signal voltage. The load of the tube Z_L may be the final output device, which is to be controlled by the signal voltage; or the output voltage from Z_L may be impressed upon another tube for additional amplification or performance of other functions before the action of the signal reaches the final output device. If the output voltage is transmitted to another tube, voltage amplification is being employed, *i.e.*, the useful output is a voltage E_{Z_L} that varies with the signal voltage but with much greater magnitude of variation. If the load Z_L constitutes the final output device to be controlled by the signal voltage, then the tube is being employed as a power amplifier, *i.e.*, the useful output is the power of Z_L. The power of Z_L will vary with the signal voltage but will possess much greater power than that of the input signal in R_g. Thus a signal possessing very little power may be amplified to control much greater amounts of power, capable of operating electromagnetic devices.

If the amplifier tube is operated on a straight portion of anode-current versus grid-voltage curve of the tube, the variations of the anode current will be in direct proportion to variations in the signal voltage. The point on the characteristic at which the tube operates is controlled by the value of the grid-bias voltage E_c employed.

An electronic amplifier employing only one tube is called a single-stage amplifier. One with two tubes operated in cascade, *i.e.*, one tube feeding into the next, is called a two-stage amplifier, etc.

53. Amplifier Coupling.—Where one stage of amplification is sufficient, the amplifier circuit is relatively simple, as shown in Fig. 60. When more than one stage of amplification is necessary, the variations produced in the anode circuit of one tube must be coupled in a satisfactory manner to the grid circuit of the next following tube. The two most commonly employed methods of amplifier coupling are resistance-capacitance coupling and transformer coupling.

A resistance-capacitance-coupled two-stage amplifer is shown in Fig. 74. With this type of coupling, a common voltage supply can be employed for the plate circuits of all the tubes. The signal voltage impressed across Z_{g_1} varies the grid voltage of the first tube, which in turn produces amplified variations in the anode current of the first tube. As the anode current of the first tube varies, the potential from point a to point b will vary. From a study of the circuit it is seen that the circuit consisting of the coupling or blocking capacitor C and resistor R_{g_2} is in parallel with the

circuit from a through the impedance Z_{L_1} and d-c supply to point b. Any constant voltage from a to b will not affect the circuit through C and R_{g_2} since the coupling capacitor C will block the passage of direct current.

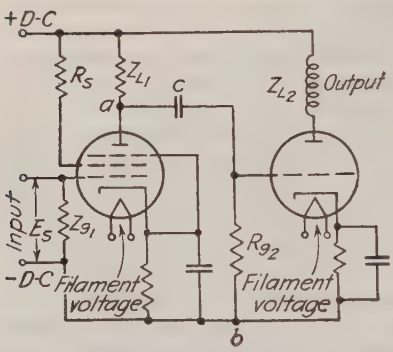


FIG. 74.—Resistance-capacitance-coupled two-stage amplifier.

Any variations in the voltage from a to b, however, will affect the circuit through C and R_{g_2} and will produce variations in the voltage across R_{g_2}. The amplified variations in the anode current of the first tube will therefore set up corresponding variations in the voltage across R_{g_2}. But R_{g_2} is in the grid-control circuit of the second tube. The amplified variations of the signal voltage are therefore transmitted to the control grid of the second tube, which in turn will produce amplified variations of its anode current through Z_{L_2}. The impedance Z_{L_1} is generally a resistance, but an inductance can be employed.

A transformer-coupled two-stage amplifier is shown in Fig. 75. The amplified variations in the anode circuit of the first tube result in the production of voltage variations across the primary of the coupling transformer which are reproduced in increased magnitude in the secondary of the coupling transformer. Since the secondary is in the grid-control circuit of the second tube, the variations of the signal voltage are passed on in amplified form to the grid of the second tube. The second tube in turn will produce amplified variations of its anode current through Z_L. Transformer-coupled amplifiers produce a greater over-all amplification than do capacitance-coupled ones when the same tubes are employed. On the other hand, the transformer-coupled amplifier is more expensive to build and does not give such faithful reproduction of the input-signal variations.

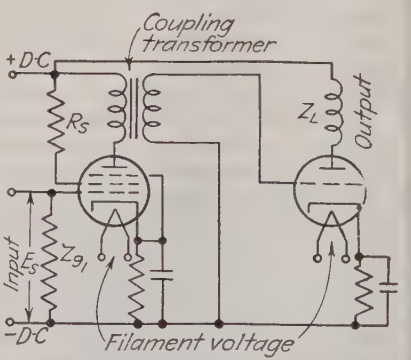


FIG. 75.—Transformer-coupled two-stage amplifier.

54. Push-pull Amplifiers.—The final stage of a power amplifier generally functions in what is called push-pull. The push-pull amplifier con-

nection, shown in Fig. 76, provides greater power output with less distortion of the signal than can be obtained with the final stage employing only one tube. The push-pull stage of an amplifier is transformer-

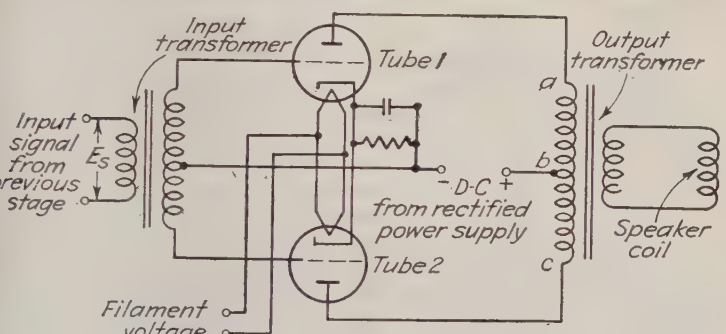


Fig. 76.—Push-pull amplifier stage.

coupled to the anode circuit of the preceding stage. With respect to the grid circuits of the two tubes, the signal voltage on tube 1 will be positive when the signal voltage on tube 2 is negative; and, similarly, the signal voltage on tube 1 will be negative when the signal voltage on tube 2 is positive. Thus the alternating current in *ab* will be 180 degrees out of phase with the current *cb*. But the two primaries *ab* and *cb* of the coupling transformer are so wound on the transformer core that, when the currents *ab* and *cb* are 180 degrees out of phase with each other, they will aid each other in producing flux in the transformer. The two tubes therefore work together to produce variations in the secondary of the output transformer in accordance with the variations of the signal voltage E_s.

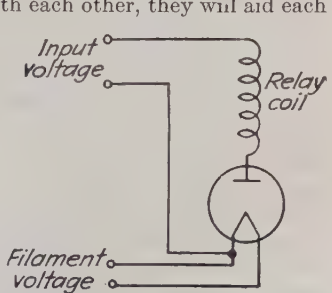


Fig. 77.—Diode functioning as a relay.

55. Electron Tubes as Relays.—Refer to Sec. **235** of Div. **7** for a definition of a relay. Any electron tube can perform the function of a relay. The only function a phototube can perform is that of a light-sensitive relay. Variations of light incident upon the cathode produce variations in the current of the phototube, and this current controls the operation of some other device. Diode tubes of the other types, although capable of performing relay function, do not lend themselves to so varied a field of relay application as do triodes. Variations in the voltage applied to the diode circuit will produce variations in the current of the circuit which may be used to control some other device. The

fundamental circuit for a diode functioning as a relay is shown in Fig. 77. An example of a diode gas-filled tube used for its relay function is the diode control tube in the ignitor circuit of the ignitron of Fig. 46. The diode operates through variations of the supply voltage to control the operation of the other device, the ignitron.

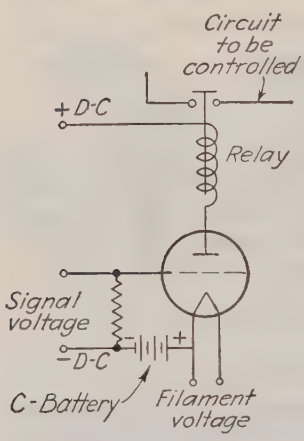


FIG. 78.—Triode functioning as a relay.

Any grid-controlled tube is admirably suited for fulfilling the function of a relay. Variations in the grid circuit produce variations in the anode circuit, which in turn may control some other device. Any tube in an electronic amplifier is in fact functioning as a relay, since variations in the grid circuit of the tube affect the operation of the next tube or of whatever device is connected in the anode circuit of the tube. However, if the primary purpose of the tube is to increase the magnitude of a signal, the function of the tube would be classified as amplification rather than relay function. Although every amplifier is really a relay, its primary function is not the relaying of the signal but the amplification of the signal. Tubes are often used in relay circuits in conjunction with electromagnetic relays. The signal is impressed on the grid of the tube, and the operating coil of the electromagnetic relay is connected in the anode circuit of the tube, as shown in Fig. 78. The signal voltage is amplified through the tube so that there will be sufficient power to operate the electromagnetic relay. If the tube is used in this manner simply because the signal voltage is not sufficiently great or does not have power enough to operate the electromagnetic relay directly, the function of the tube is not primarily relay function but is really amplification. The fundamental circuits for triode tubes functioning as relays are shown in Figs. 79 and 80. The input or initiating device of the relay may consist of some signal voltage, as in Fig. 79; or it may be a mechanically controlled contact, as in Fig. 80.

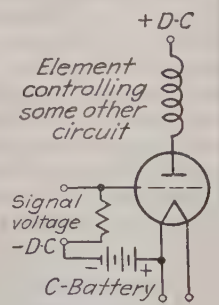


FIG. 79.—Circuit for controlling current through a load using a triode as a relay.

Electron tubes are very advantageous as relays for applications where the initiating of the functioning of the relay is produced by a delicate mechanically controlled contact device. If the delicate contacts are connected directly in series with the operating coil of an electromagnetic

relay, the sparking at the contact points will in time oxidize the contact surfaces. This oxidation will eventually increase the resistance in the coil circuit so that the relay will not operate. If a triode vacuum tube is used, as shown in Fig. 80, the initiating contacts carry a current so small that no arcing will occur. An electronic relay of this type can also be employed when the control contacts must work in an explosive atmosphere.

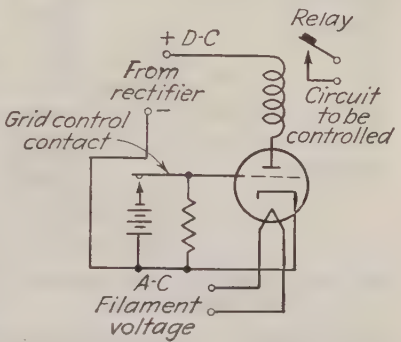


FIG. 80.—Grid-contact relay circuit.

56. Light-sensitive Relays.—Phototubes find a wide field of application in light-sensitive relays. Generally, the power output of a phototube is not sufficient to operate the controlled device, such as a magnetic contactor or switch, directly. Photoelectric relays therefore generally employ an amplifying tube in conjunction with the phototube and an electromagnetic contactor or relay. The principles of operation of light-sensitive relays, employing phototubes and one stage of amplification, are shown in Figs. 81 and 82. The circuit of Fig. 81 functions to close the relay when sufficient light falls on the phototube cathode, whereas the circuit of Fig. 82 functions to close the relay upon decrease in the light incident upon the phototube. In the circuit of Fig. 81, when light falls on the cathode of the phototube, current is produced from the battery through the phototube and coupling resistor. The current in the coupling resistor makes the grid of the triode vacuum tube more positive (less negative) and thereby increases the anode current of the tube. If this increase in the anode current is sufficient, the electromagnetic relay will close. In the circuit of Fig. 82, the electromagnetic relay is closed by the anode current of the triode vacuum tube, when there is no light on the phototube. Light on the cathode of the phototube producing current through the coupling resistor makes the grid of the triode vacuum tube

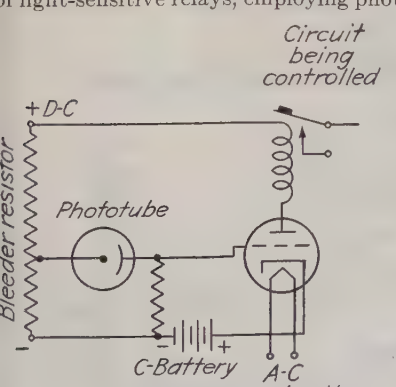


FIG. 81.—Positive phototube-controlled relay circuit.

more negative and thereby reduces the anode current of the triode. The electromagnetic relay will open when the light is sufficient to reduce the anode current of the triode vacuum tube to a point that will not hold the relay closed.

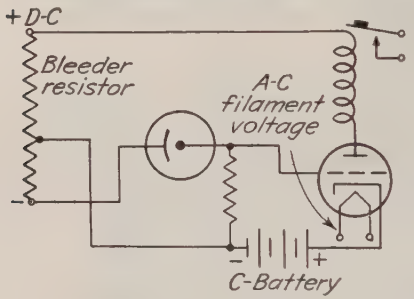


FIG. 82.—Negative phototube-controlled relay circuit.

The circuits of actual commercial photoelectric relays are more complicated than those of Figs. 81 and 82 because of the necessary additional tubes, resistors, and capacitors required for producing the voltage supplies for the phototube and amplifier tube. The panel wiring diagram of a fairly simple commercial phototube relay is shown in Fig. 83. Figure 84 shows the circuit diagram of this relay with

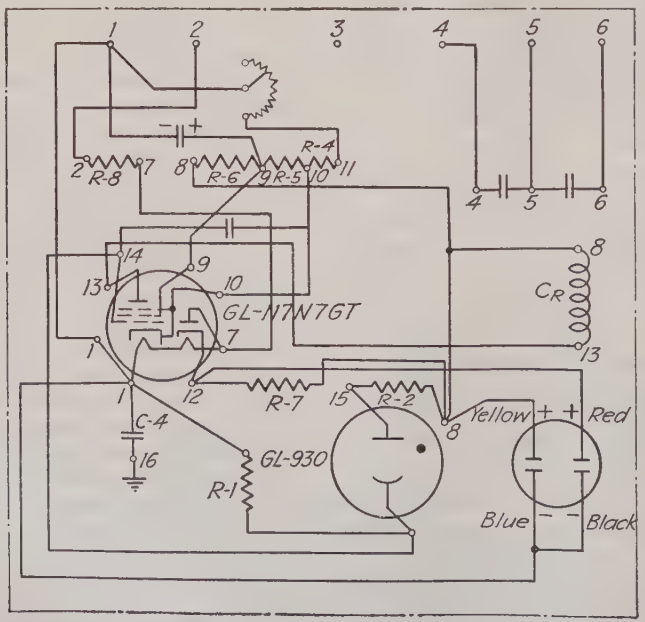


FIG. 83.—Panel wiring diagram for a photoelectric relay. (Bottom view.)

the parts rearranged so that the diagram is simplified and it is easier to study the purpose and functioning of the different parts.

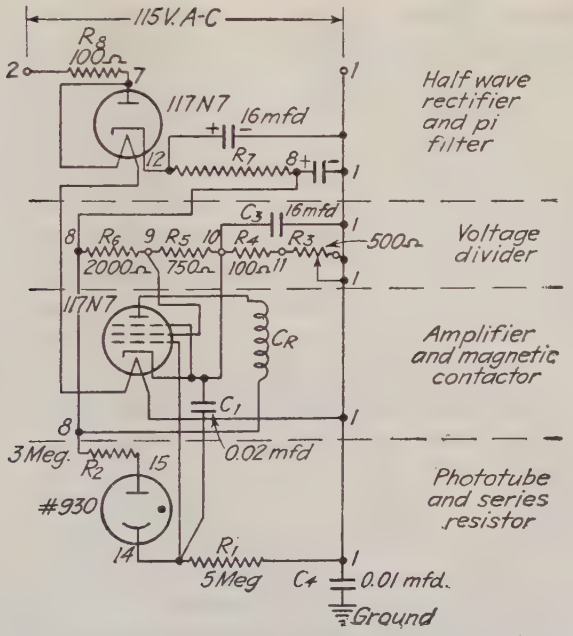


FIG. 84.—Schematic circuit of the panel diagram of Fig. 83.

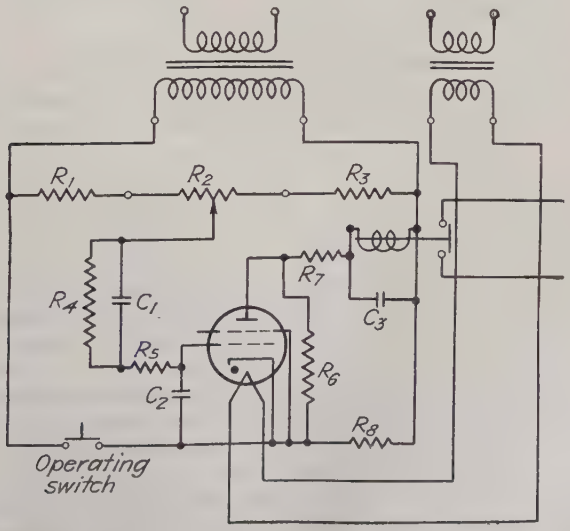


FIG. 85.—Electronic timer circuit.

57. Electronic Timers.—An important application of the relay function of tubes is in electric time-delay relays. These relays are often called electronic timers. Electronic timers provide time delay by controlling the conduction of an electron tube in accordance with the time required for the charging or discharging of a capacitor. The principles of an electronic timer are illustrated by the circuit of Fig. 85. This is a basic electronic time-delay circuit which is adapted to many time-control problems. When the operating switch is open, the capacitor C_1 is charged by the a-c supply voltage through the rectifier characteristics of the thyratron grid circuit. There will be no conduction in the anode circuit of the thyratron, since the cathode is connected through resistor R_3 to the same side of the line as the anode. When the operating switch is closed, the cathode of the thyratron is connected directly to the opposite side of the line from the anode. The tube will not conduct, however, until the capacitor C_1 has discharged to a certain level through resistor R_4. After a certain time delay depending upon the setting of R_2 and the time discharge characteristic of the C_1R_4 circuit, the thyratron conducts and operates the relay.

58. Electron Tubes as Swtiches or Contactors.—Compared with other forms of switches or contactors, tubes have the advantage of not requiring the physical breaking of the connections of the circuit, do not require contacts or moving parts in the main circuit, and require only small consumption of control power. If the operation of the electronic switch is controlled by some other electron tube, then the electronic switch has the further advantage of quick response action and flexibility in circuit design and adjustment.

The reader may have some difficulty in distinguishing between switch and relay action. An electric switch is a device that functions to start or stop conduction in a circuit through the functioning of some auxiliary circuit. In a magnetic contactor or switch, the function is to open or close the contacts of the device through the action of the operating coil of the device. In the electronic switch, the function is to stop or start conduction in a circuit connected in series with the anode circuit of the tube. This switching action is produced through the action of the (auxiliary) grid circuit of the tube. A relay within itself does produce switch action, but it does not directly function as a switch in the main circuit to be controlled. The relay is an intermediate device that functions to cause the operation of some other device but does not itself open or close the main circuit

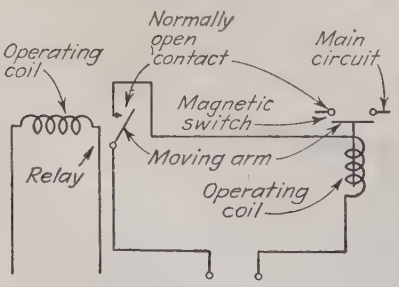


FIG. 86.—Distinction between a relay and a magnetic switch.

that is to be controlled. A study of Fig. 86, which shows the function of an electromagnetic relay and a magnetic switch, should help in clarifying the distinction between a relay and a switch.

Any grid-controlled vacuum tube may be used to function as a switch or contactor for a d-c circuit.

A circuit for a triode vacuum tube employed as a switch is shown in Fig. 87. When the control contact in the grid circuit is closed, the tube will be biased to cut off, and no current will flow in the main circuit. When the control contact is open, there will be zero bias voltage, and the main circuit will pass current. Although the circuit of Fig. 87 probably has

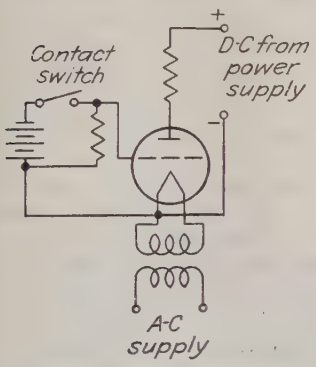


FIG. 87.—Electronic switch.

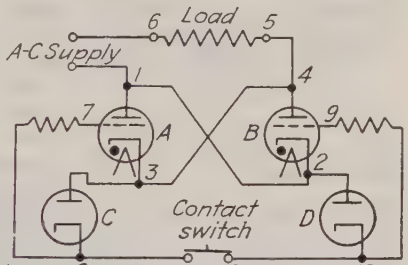


FIG. 88.—Thyratron tubes in inverse parallel controlled by diode rectifiers.

little or no practical importance in itself, it will aid in obtaining an understanding of the functioning of an electron tube as a switch.

In any ignitron-tube rectifier circuit, the tube will function as a switch in the main circuit. When the ignitor circuit is closed, the main circuit will be conducting; and, when the ignitor circuit is open, no current will flow in the main circuit.

Tubes are seldom used in d-c circuits for the primary function of a switch, but, when tubes are used as rectifiers, the switch function of the tube can often be employed advantageously.

An electronic switch for an a-c circuit can be constructed by connecting two thyratron or ignitron tubes in inverse parallel in series with a circuit. Inverse-parallel connection of tubes is formed by connecting the tubes in parallel with the cathode of each tube connected to the anode of the other tube. The operation of the electronic a-c switch requires the use of contact rectifiers or of two diode tubes functioning as relays to control conduction of the main tubes. If thyratrons are used for the main tubes, they must be of the type that requires a positive grid for conduction to take place when the voltage of the main circuit is impressed on the cathode-anode circuit. The relay tubes may be vacuum or gas-filled

depending upon the current requirements of the relay tubes. Typical circuits for electronic a-c switches or contactors are shown in Figs. 88 to 91. In all these switches, when the contact switch is open, the grid or ignitor circuits will be open. There will therefore be no conduction in the main switch tubes, and the main circuit will be "open," *i.e.*, there will be no current in the main circuit. When the contact switch is closed, the diode-controlled switches of Figs. 88 and 89 will function as follows: When point 1 is at positive polarity, current will pass from point 1 to 2, through diode *D* to point 10, through the contact switch to point 8, to point 7, and through the grid or ignitor circuit to point 3, to point 4, and through the load and back to the other side of the line at point 6. This will fire tube *A*, and current will then pass in the main circuit from point 1 through tube *A* to point 3, from point 3 to point 4, through the load, and back to the negative side of the line at point 6. This will be the conduction path for the half cycle when point 1 is of positive polarity. When point 6 is at positive polarity, current will pass from point 6, through the load to point 4, to point 3 and through diode *C* to point 8, through the contact switch to point 10, to point 9 through the grid or ignitor circuit to point 2, and back to the other side of the line at point 1. This will fire tube *B*, and current will pass in the main circuit from point 6 through the load to point 4, through tube *B* to point 2, and back to the other side of the line at point 1. This will be the conduction path for the half cycle when point 6 is of positive polarity. Thus, when the control switch is closed, the electronic switch, composed of tubes *A* and *B*, allows current to pass in the main circuit during both the positive and negative half cycles; and, when the control switch is open, no current is allowed to pass in the main circuit.

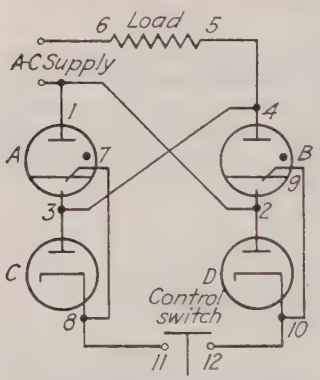


FIG. 89.—Ignitron tubes in inverse parallel controlled by diode rectifiers.

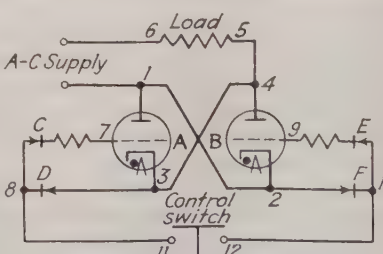


FIG. 90.—Thyratron tubes in inverse parallel controlled by contact rectifiers.

The contact-rectifier-controlled switches of Figs. 90 and 91 operate in the following manner: When the contact switch is closed and point 1 of

the line is at positive polarity, current will pass from point 1 to point 2, through the contact rectifier F to point 10, through the contact switch to point 8, through the contact rectifier C to point 7, through the grid or ignitor circuit of tube A to point 3, to point 4, through the load, and back to the other side of the line at point 6. This will fire tube A, and current will pass through the main circuit from point 1 through tube A to point 3, to point 4, through the load, and back to the other side of the line at point 6. When the contact switch is closed and point 6 of the supply is at positive polarity, current will pass from point 6 through the load to point 4, to point 3, through the contact rectifier D to point 8, through the contact switch to point 10, through the contact rectifier E to point 9, through the grid or ignitor circuit of tube B to point 2, and back to the other side of the line at point 1. This will fire tube B, and current will pass in the main circuit from point 6, through the load to point 4, through tube B to point 2, and back to the other side of the line at point 1.

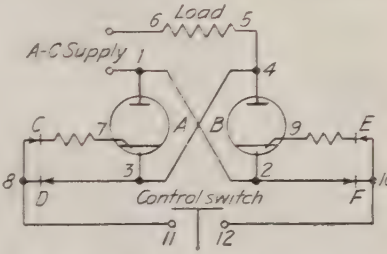


FIG. 91.—Ignitron tubes in inverse parallel controlled by contact rectifiers.

An electronic switch for a-c circuits can be used for the control of the current of the circuit in addition to its plain switch function. This feature is the great advantage of the electronic switch. The electronic switch is often used in a-c circuits, when it is desired to control the average value of the current within close limits or to control the time of conduction in the circuit. The principal application of the a-c electronic switch is in the control of resistance welding circuits. With the a-c electronic switch, the current of the circuit can be controlled by using thyratron tubes as the relay tubes in the ignitor circuits for the control of the firing of the ignitor switch tubes. Through grid control of the thyratrons, the period of conduction throughout the positive half cycle of each ignitron tube can be controlled. The circuit for such an electronic switch would be the same as shown in Figs. 88 and 89, with the addition of the grids and the grid-control circuits for the relay tubes. Refer to Sec. **33** for typical grid-control circuits. Another method for the control of the current with an electronic a-c switch is to remove the contact switch of Figs. 88 to 91 and connect the terminals 11 and 12 to an external control circuit, such as an electronic timer. Through an external control circuit and an electronic timer, not only may the average current of the main circuit be controlled, but also accurate timing of the conduction period may be obtained. This is the method so often employed for the control of electric resistance welding.

Another electronic contactor that gives partial switching action and will provide a method of controlling the average value of the current is shown in Fig. 92. When the thyratron tubes are not passing current, there will be no current in the secondary of the series impedance transformer. This transformer is then operating with open circuit secondary, and the primary of the transformer will introduce a high impedance into the main circuit. This is the "off" condition of the switch. This electronic switch has the disadvantage that the current in the circuit is not completely stopped in the "off" condition of the switch. However, the current is reduced to a very low value, which is satisfactory for certain applications, as in some welding circuits. When the thyratrons are conducting, they will practically short-circuit the secondary of the series impedance transformer and thereby reduce the impedance introduced by the primary in the main circuit to a very low value. By controlling the conduction periods of the thyratrons, the average value of the impedance introduced into the main circuit can be controlled. By this means, the contactor can control the average value of the current of the main circuit.

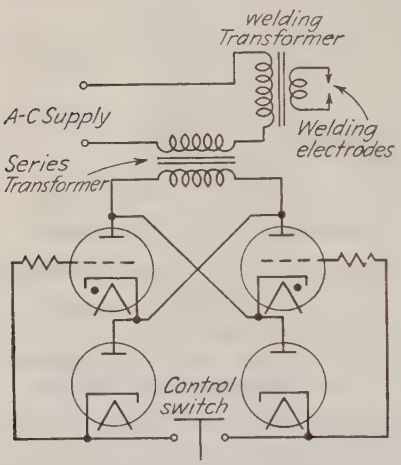


FIG. 92.—Circuit for welding control using series transformer and thyratron tubes.

59. Electron Tubes as Oscillators.—In the electrical sense of the word, oscillation is the periodic changing of a voltage or a current. An oscillator is a device for the production of an alternating voltage by means of setting up oscillations in a circuit that is energized from a d-c source.

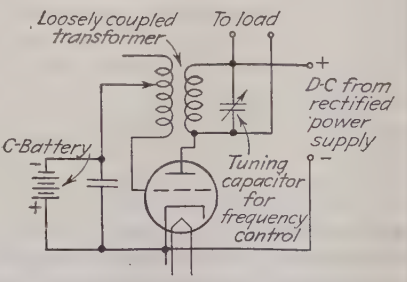


FIG. 93.—Tuned anode circuit oscillator.

Oscillators are used as the generating means for alternating voltages of frequencies higher than those which can economically be produced by alternators. An important application of grid-controlled vacuum tubes is as the activating device to produce the necessary oscillations in oscillator circuits.

The amplifying effect of the control grid makes it possible to produce oscillations with a vacuum tube. The oscillations are produced by bleeding off a small amount of energy from the anode circuit and feeding this energy back to the grid circuit in proper amount and phase relation. The frequency of the oscillations can be controlled by a resonant circuit located in the grid circuit, in the anode circuit, or in both the grid and anode circuits. A resonant circuit is one containing both inductance and capacitance and in which the effect of inductance and capacitance just neutralize each other. The frequency of oscillations produced by an oscillator

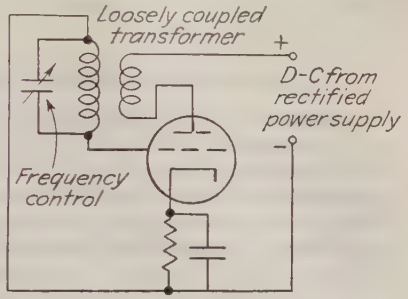


FIG. 94.—Tuned grid circuit oscillator.

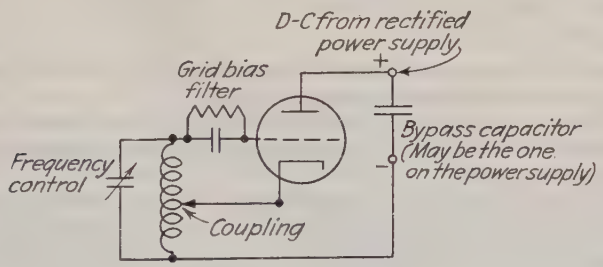


FIG. 95.—Hartley oscillator.

are controlled by adjusting the relative values of the inductance and capacitance of the resonant circuit. Fundamental oscillator circuits are shown in Figs. 93 to 96. In many practical oscillator circuits, one resonant circuit, or tuned circuit, as it is often called, frequently is used to serve in both the grid and anode circuits, as shown in Fig. 95.

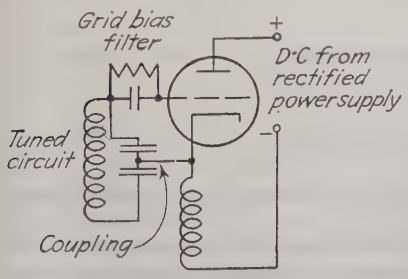


FIG. 96.—Colpitts oscillator.

Vacuum-tube oscillators, in addition to their wide application in communication work, are used in industrial control circuits and are the main source of high-frequency voltage employed for high-frequency industrial heating (see Sec. **66**).

60. Electron Tubes as Modulators and Detectors.—The application of electron tubes for the function of modulation and detection is confined entirely to communication work. A discussion of these functions is outside the scope of this book.

ELECTRONIC CIRCUITS AND APPLICATIONS

61. Electronic circuits and applications are so numerous and varied that it is impossible in the space available in this book to do more than to give some helpful suggestions in the method of procedure for analyzing any particular circuit, the general fields of application, and explanation of the circuits for some typical examples.

62. Method of Analyzing Electronic Circuits.—In the application of electron tubes to industry, the complete electronic circuit consists of a combination and elaboration of the basic circuits already discussed, in many cases with the addition of special refinements. Understanding these circuits directly from the actual wiring of the device or from the usual wiring diagram is difficult. However, with the aid of the following procedure, analyzing the functioning of the devices and their operation should not be too difficult.

A. Make a wiring diagram from the connections of the device, if such a diagram is not already available.

B. Study the wiring diagram, and determine the primary function of the different tubes such as power-supply rectifier, amplifier, relay switch, or oscillator.

C. Study the wiring diagram, and determine if possible the purpose of the different circuit elements such as resistance, inductance, and capacitance. As a help in this determination, a summary of the more common purposes for which the different elements are employed follows:

1. Resistance elements.
   - *a.* Voltage divider sections.
   - *b.* Grid-bias resistor.
   - *c.* Screen-grid resistor.
   - *d.* Series resistor in grid circuits for limitation of grid current.
   - *e.* Series resistor in phototube circuits.
   - *f.* Coupling resistor.
   - *g.* Resistance arm of phase-shift circuit.
2. Capacitance elements.
   - *a.* Filtering element for filtering of voltage from rectified power supply.
   - *b.* Filtering element across voltage supply to a varying load.
   - *c.* By-pass capacitor across portion of circuit to maintain constant current in portion by-passed.
   - *d.* Coupling and blocking capacitor for coupling variations of one

circuit to another while at the same time blocking transfer of direct current.

e. Capacitor arm of phase-shift circuit.

3. Inductance elements.
   a. Filtering elements for filtering of voltage from rectified power supply.
   b. Inductance arm of phase-shift circuit.
4. Redraw the circuit segregating the parts according to their respective functions. Arrange the diagram so as to show in the simplest manner the purpose of each part and the over-all functioning of the circuit.
5. Study the simplified diagram of 4, and determine the method and sequence of operation.

In the study of the wiring diagram, all the tubes employed should first be determined. The general type of each tube will be indicated by the symbol by which it is represented in the wiring diagram. Then the function for which each tube is employed should be discovered, followed by the determination of the general function of the circuit elements. In planning the general arrangement of the simplified circuit diagram, one good procedure is to start at the top of the diagram with the power supply, followed by power-supply transformers, cathode-heating circuits, rectifier for power supply to anodes and grids, power-supply filter, voltage divider, and then the anode and grid circuits of the individual tubes. The circuits of the different tubes should be segregated from each other and arranged in as logical an order as is possible in accordance with the sequence of operation. Before the circuit is redrawn, an estimate of the space that will be required should be made and then a sheet of paper about twice the size estimated should be used. The general tendency is to underestimate the space required; consequently, as the drawing progresses, it becomes necessary to crowd the different parts. Crowding of the diagram often results in errors and always hampers the study and understanding of the circuit. When the sheet has been selected, the space for the sections should be indicated and the tubes located in their respective sections. Then the connections from the original wiring diagram should be transferred to the new simplified one. In doing this, care should be taken to lay out the diagram so that it will be as open, clear, and with as few crossing connections as possible. Generally it will be advisable to redraw the diagram after the first attempt in order to get desired results of clarity and simplicity of arrangement. A study of Figs. 83 and 84 will help in understanding the method of procedure. The original wiring diagram of the device is shown in Fig. 83 and the corresponding rearranged diagram in Fig. 84.

63. Applications of Electron Tubes and Circuits.—Some of the more important industrial applications of electron tubes and circuits are

1. Rectifiers. Refer to Secs. **46, 47, 48,** and **51.**
2. Motor-speed regulators. Refer to Secs. **138** and **156** of Div. **7.**
3. Automatic electric-drive control. Refer to Sec. **140A** of Div. **7.**
4. Register regulators. Refer to Sec. **64.**
5. Resistance-welding control. Refer to Sec. **65.**
6. High-frequency heating. Refer to Sec. **66.**
7. Light-sensitive control devices. Refer to Sec. **67.**
8. X-ray equipment. Refer to Sec. **27.**
9. Voltage regulators. Refer to Sec. **68.**

64. Register regulators are devices for the automatic position control of processes performed upon moving webs, such as paper, cloth, and sheet

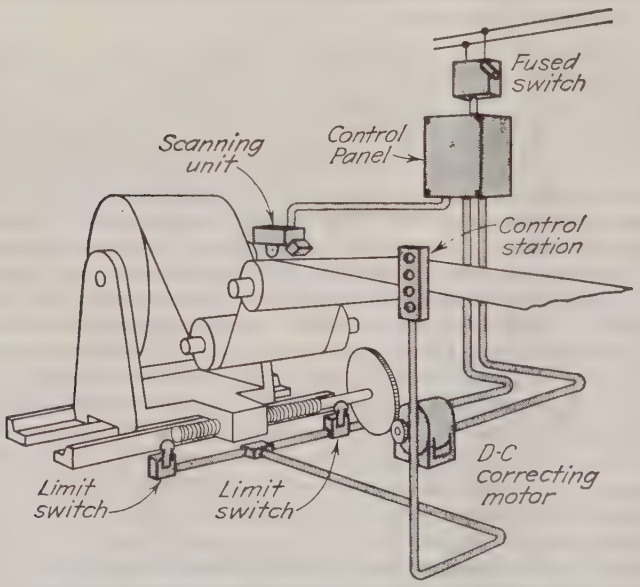


FIG. 97.—Arrangement of equipment for side register control.

metal. The web material to be processed is wound on rolls and fed through the processing machines. Some of the processes in which it is necessary to control the position of the material automatically are cutting, printing, slitting, trimming, and rewinding. Register regulators may be divided into two types, forward-position regulation and lateral, or side-position, control.

The general purpose of the forward register control is to control the process of cutting or printing of the material so that the operation is performed at the proper position on the sheet of material as it is fed

through the machine. Spots are previously printed on the material, or holes are punched in it to designate the proper position of the operation on the web. These spots or holes are scanned by a phototube. The phototube controls an electronic circuit so as to synchronize the position of the material with the operation of cutting or printing. Many different circuits and arrangements of equipment have been employed for this synchronization. A discussion of them is beyond the scope of this book.

Side register control keeps the lateral position of the material in a given relation to the processing machine. In this control, a phototube scanning head observes the position of the edge of the moving web, or a printed line on the web, and produces a signal voltage whenever the lateral position deviates from the correct location. This voltage is indicative of the direction and the amount of deviation of the web from the desired position. The signal from the scanning head is amplified by an electronic amplifier and is used to control either contactors or the correcting motor directly, or to excite the field of a control generator. The elements of a side register control are shown in Fig. 97. The correcting motor, when started by a signal from the phototube scanning head, will function to shift the web until the material has been brought back to the correct position, when the phototube scanner will no longer be energized.

65. Resistance-welding Control.—To join two metals by the resistance-welding method, the two parts to be welded are clamped together under pressure, and a definite value of current is then passed through the junction of the two parts for a specified length of time (see Fig. 98). If the heat generated as a result of the I^2R losses is great enough and the duration of the current is long enough, the metal reaches the fusion temperature at the interface of the parts. To make consistently good welds, it is necessary to have control over the current density in the metal, the length of time the current is applied, and the resistance at the interface of the metals relative to the contact resistance between the electrodes and the metals. The basic equipment for resistance welding is shown in Fig. 99.

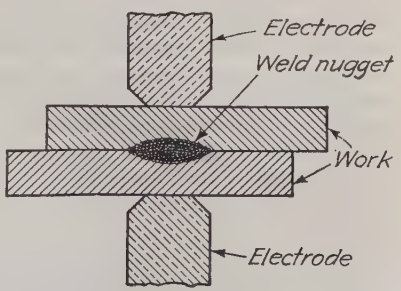


FIG. 98.—Cross section of a typical weld.

If the surfaces of the metal and the electrodes are clean (which is usually the case), the question of the resistance of the metal is reduced to determining ways to keep a constant, adequate pressure on the work. If the pressure is kept constant, the resistance effects caused by changes in pressure are constant.

One way commonly used to apply pressure to the work by the electrodes is illustrated in Fig. 99. In this system, the work is placed between the electrodes, one of which is stationary. The other electrode is rigidly fastened to the movable piston in an air cylinder. The upper and lower chambers of the cylinder are connected to a four-way solenoid air valve. If the solenoid valve is energized, air is released from the lower chamber and directed into the upper chamber. The piston moves downward, and the upper electrode touches the work and builds up a

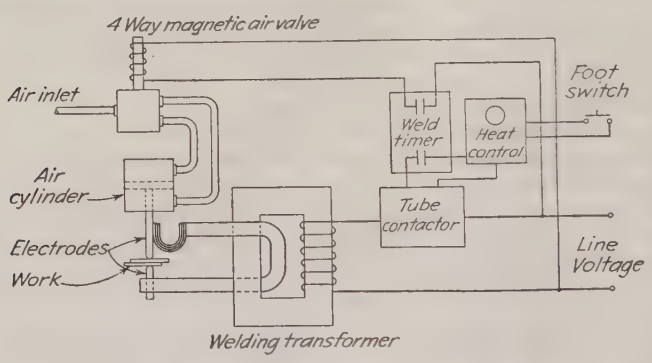


FIG. 99.—Basic equipment for resistance welding.

pressure on it. The pressure developed depends on the controlled air pressure and the electrode diameter. When it is desired to release the pressure, the electric solenoid valve is de-energized by breaking the contact in series with the solenoid. This causes the valve to assume its normal position. Air is discharged from the upper chamber of the cylinder and enters the lower chamber.

The current density and the length of time current is applied usually are controlled by electronic means. The necessary equipment consists of an electronic contactor (refer to Sec. **58**), controlled through a heat-control unit and a weld timer. The heat-control unit controls the average value of the welding current throughout the duration of the welding time, and the weld timer controls the length of time current is applied. A complete circuit for a resistance welder is shown in Fig. 100.

The heat-control unit is an electronic contactor, consisting of two shield-grid thyratrons (tubes T_{U_1} and T_{U_2}) connected in inverse parallel in series with the ignition circuit of the main ignitron contactor. The point of firing of the ignitrons is thus controlled by the heat-control electronic contactor. The portion of each cycle that the heat-control contactor is closed will thus govern the average welding current. The conduction period of the thyratrons of the heat-control contactor is adjusted by an *RL* phase-shift circuit, as shown in Fig. 100.

The phase-shifting apparatus employed in the heat-control unit consists of a reactor L_1 and resistor R_3 in series across the terminals of the power-supply transformer. The heat-control potentiometer is connected between the mid-tap of the resistors, and one of the taps between 0.20 to 0.80 of the reactor. Voltages across the reactor and across the resistors are 90 degrees out of phase with one another. The voltage taken between any point on the reactor or the resistors and the mid-tap of the transformer secondary lags line voltage. The reactor is calibrated so that the voltage between tap 0.30, for example, and connection 14 lags the line voltage by an angle corresponding to a 30 per cent power-factor angle. This is the significance of the reactor tap markings, *i.e.*, they are power-factor markings. Voltage between the resistor mid-tap and the center tap of the transformer secondary lags line voltage by 135 degrees.

Heat-control potentiometer P_1 is connected between that reactor tap marked by the power factor of the welding machine, and the resistor mid-tap. Output voltage of the heat-control circuit is taken from P_1 to the transformer secondary mid-point. Hence, in moving the slider of the heat-control potentiometer from left to right, the ignition point is retarded from that delivering maximum full-wave welding current to a point 135 degrees lagging the line voltage. Effective welding current, regardless of machine power factor, is correspondingly lowered.

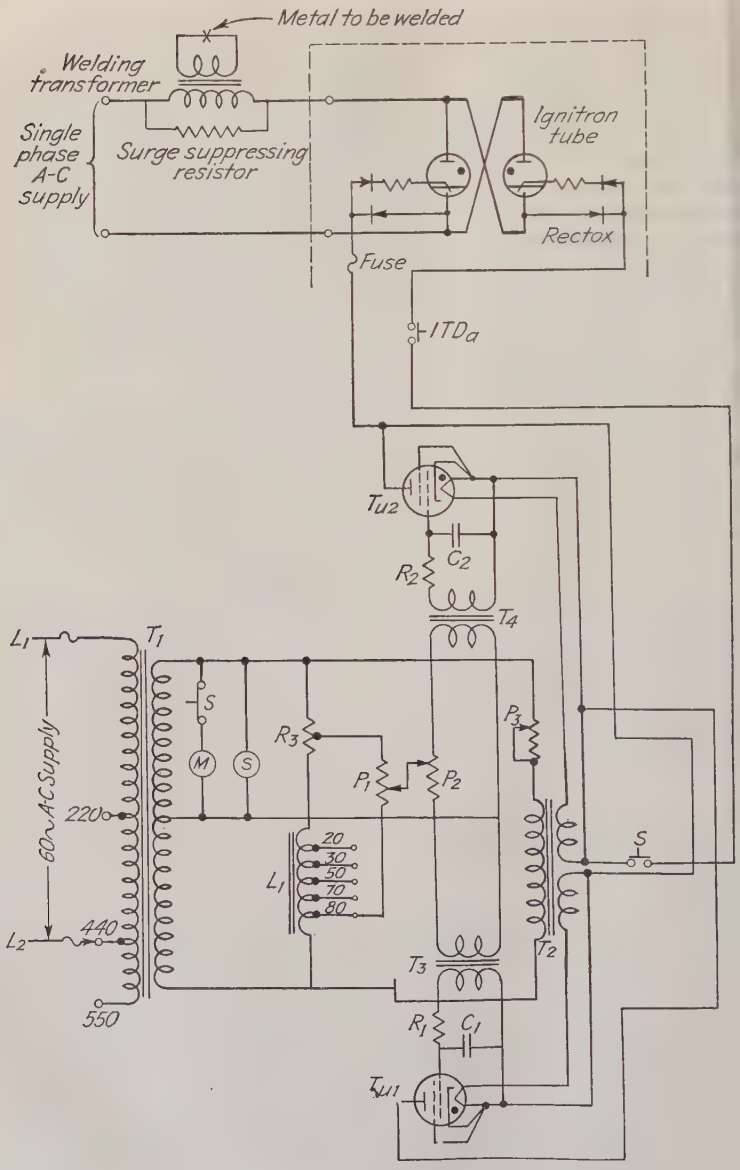
The two grid transformers serve two purposes: (1) they reverse the phase of the voltage delivered to the grid of one tube with respect to that delivered to the other tube, since the anode-cathode voltages of these tubes are also 180 degrees apart; and (2) they insulate the grid circuits of these tubes, since the filaments are connected to opposite line-voltage terminals.

The function of potentiometer P_2 is to compensate for any variation in positive and negative currents that flow through the welding transformer. If the currents are the same, the slider on P_2 is at the mid-point. If the positive and negative current loops are unequal, the slider is moved to delay the firing of one heat-control thyratron and advance the firing of the other.

Potentiometer P_3 is in the primary circuit of the transformer supplying filament power for the thyratron tubes. By means of it, the voltage applied to the tube filaments can be held constant with a supply-voltage fluctuation of as much as from 85 to 110 per cent of the nominal value.

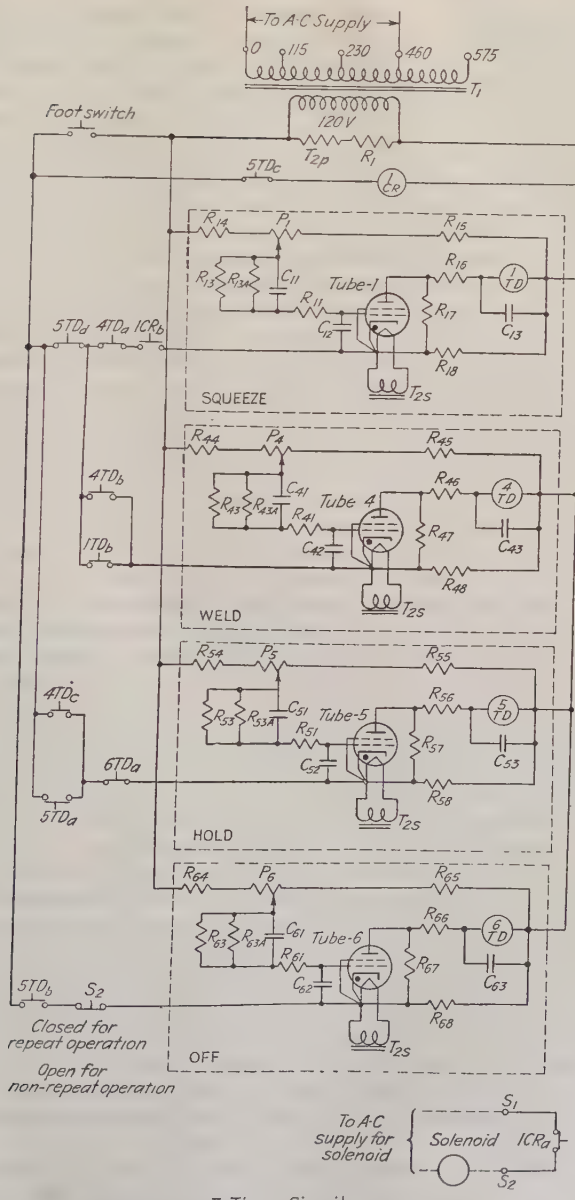
The weld timer consists of four identical electronic timers. The principle of operation of each timer is the same as for the timer discussed in Sec. **52.** Such a timer is used to control automatically a four-operation welding cycle consisting of squeeze, weld, hold, and off periods.

When the initiating foot switch is closed, a contact closes in the circuit of the solenoid and causes welding-machine electrodes to close on the work and apply pressure to the metal to be welded. After a preadjusted interval, a second contact energizes the ignition circuit of the main



I. Main welding and ignition circuit

FIG. 100. Part I.—Weld-o-Trol. (*Westinghouse Electric & Manufacturing Co.*)



II. Timer Circuit

FIG. 100. Part II.—Weld-o-Trol. (*Westinghouse Electric & Manufacturing Co.*)

ignition contactor. This allows current to flow through the primary of the welding transformer. After another interval, the contactor in the ignition circuit opens, and weld current ceases. A third time interval follows the cessation of welding current, at the end of which the contactor in the solenoid circuit opens, and the electrodes of the welding machine separate. At the same time, a set of contacts opens and prevents operation of the solenoid until a fourth period of time has elapsed, following which the entire cycle is repeated. This process is repeated as long as the foot switch is closed.

P_1 controls the length of the squeeze period, P_4 the length of the weld period, P_5 the length of the hold period, and P_6 the length of the off period.

If the foot switch is closed, $1CR$ becomes energized, and contacts $1CRa$ and $1CRb$ close. Contact $1CRa$ operates the welding-machine solenoid; $1\ CRb$ allows the grid capacitor C_{11} of tube 1 to discharge. After C_{11} has discharged sufficiently, tube 1 fires.

This energizes $1TD$ and causes its contacts $1TDa$ and $1TDb$ to close. Contact $1TDa$ is in the ignition circuit of the ignitrons of the main contactor. Welding current then flows under the control of the heat-control unit, as previously explained.

$1TDb$ allows the grid capacitor C_{41} of tube 2 to discharge. After C_{41} has discharged sufficiently, tube 4 fires and energizes $4TD$.

At this point, $4TDa$ opens. Since these contacts are in series with ITD, $1TD$ drops out and causes $1TDa$ to open and interrupt the welding current. At the same time, $4TDb$ and $4TDc$ close. Contact $4TDb$ is a lock-in contact and has no effect on the sequence; $4TDc$ allows C_{51} to discharge.

After C_{51} has lost sufficient charge, tube 5 fires. This energizes $5TD$, causing $5TDa$ and $5TDb$ to close and $5TDc$ to de-energize $1CR$, which in turn causes the solenoid to separate the electrodes of the welding machine. $5TDd$ opens the circuit of $4TD$. $5TD_a$ is a lock-in contact and initiates no other circuit. $5TD_b$, however allows C_{61} to discharge.

When C_{61} has lost sufficient charge, tube 6 fires and energizes $6TD$. This opens $6TDa$, which de-energizes $5TD$. When the contacts of the $5TD$ relay return to their normal position, the circuit is the same as at the start, and the whole cycle is repeated as long as the foot switch is kept closed, provided that switch S_2 is closed. Switch S_2 is the repeat switch; and, when it is open it removes the circuit associated with tube 6 from the welding circuit. This means that the repetition of the welding cycle is not automatic. When switch S_2 is open, the welding cycle is repeated only after the operator releases the foot switch for a period sufficient in length to allow capacitors C_{11}, C_{41}, and C_{51} to charge and then closes the foot switch again.

66. High-frequency heating is the heating of materials through the heat generated in them by an electric source of power of high frequency.

High-frequency heating is of two types: induction heating and dielectric heating. Induction heating is employed for the heating of metals or other conducting materials. Dielectric heating is employed for the heating of poor conducting materials such as plastics and plywood.

In induction heating, the conducting material to be heated is placed inside a coil which is usually called the inductor coil. The coil is connected to a high-frequency source of voltage capable of delivering the required power. The high-frequency magnetic field produced by the high-frequency current in the inductor coil will induce voltages of the same high frequency in the material enclosed by the coil (refer to Sec. **45** of Div. 1). These voltages will produce high-frequency currents in the material to be heated. Because of skin effect (see Sec. **116** of Div. 1), these induced currents will be crowded out toward the surface of the material. The depth of the current-carrying layer will decrease as the frequency increases. Thus it is possible, by the proper choice of frequency, to control the depth to which an object is heated.

In dielectric heating, the poor conducting mass is placed between two electrodes, which are connected, respectively, to the two terminals of a high-frequency source of voltage. The electrodes and the material to be heated will constitute a capacitor, and an alternating electric field will be set up in the material between the two electrodes.

This alternating field, passing uniformly through the work, displaces or stresses the molecules of the material, first in one direction and then in the other, as the polarity of the field is reversed. Friction occurs because of this molecular motion in the work and generates heat uniformly throughout the mass. Such molecular friction and the resulting heat generation are proportional to the field reversals per second; and, consequently, the higher the frequency, the faster the heating. Because of heat radiation from the surface, however, the center may be hotter than the outer layers. Suitable measures can be taken to correct this condition when it occurs.

Oscillators are used as the source of the high-frequency power required for induction and dielectric heating (refer to Sec. **59**).

67. Light-sensitive control devices have a broad field of application in industry. The light-sensitive feature generally is obtained by means of a phototube. Since the output of most available phototubes is too low to operate sturdy electromagnetic devices, it is generally necessary to amplify the output of the phototube with an electronic amplifier of one or more stages. Refer to Sec. **56** for a discussion of light-sensitive relays. The complete circuit of a light-sensitive device may involve other tubes and circuit elements, depending upon the function to be performed. General-purpose light-sensitive relays and light sources for their operation are available which are adaptable to many conditions and can be used as the base unit in building up a complete control system. Some of the more common light-sensitive control devices are:

Limit switches.
Automatic door openers and closers.
Counting of objects on a conveyor.
Elevator-floor leveling.
Elevator-door safety control.
Automatic control of artificial lighting.
Louver controllers.
Sorting, grading, and matching.

A circuit for automatic control of artifical lighting is shown in Fig. 101. When switch S is open, relay 1 is open, and its back contacts at 62 are closed, as shown in the figure. Contactor C is also open, and the circuit

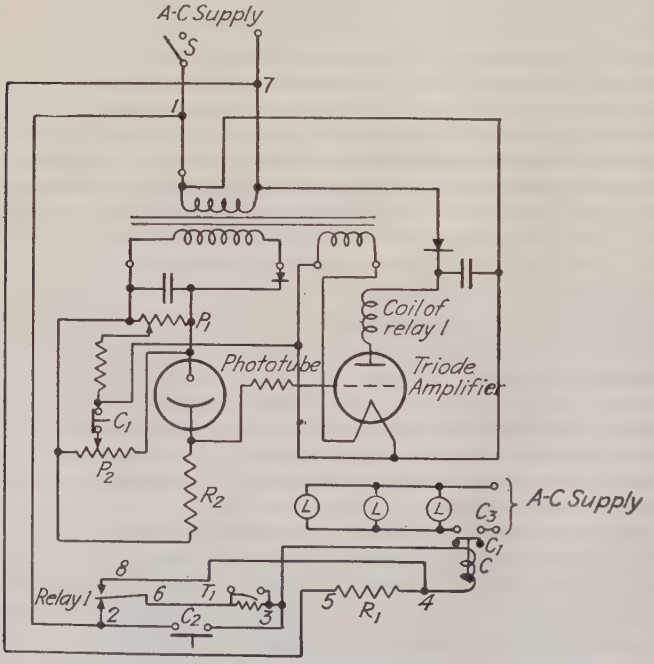


Fig. 101.—Circuit for phototube control of a lighting circuit.

to the lamps is open. When switch S is closed, current will flow from point 1 to 2, to 6 through the heating element of the thermal relay to point 3, through operating coil C of contactor C, through resistance R_1, and back to the other side of the line at point 7. However, the current through the operating coil of contactor C will not be sufficient to operate contactor C because of the resistance of the heating coil of the thermal relay. Contactor C, therefore, cannot close for a certain length of time.

Closing of switch S also energizes the grid and anode circuits of tube B. The anode current of tube B depends upon the grid voltage of the tube. The grid voltage is a combination of the grid-bias voltage and the drop in resistor R_2 caused by the current of the phototube. The circuit is so connected that the drop in resistor R_2 decreases the negative grid voltage of tube B. Thus, as illumination on the phototube increases, the anode current of tube B increases. The grid-bias voltage of tube B is adjusted through potentiometer P_1 when contacts C_1 are open and through both potentiometers P_1 and P_2 when contacts C_1 are closed. Contacts C_1 are open when contactor C is closed and the lights are on. Contacts C_1 are closed when contactor C is open and the lights are off. Therefore, the grid-bias voltage of tube B is controlled through potentiometer P_1 when the lights are on and through both potentiometers P_1 and P_2 when the lights are off. Upon closing switch S, if the illumination on the phototube is sufficient, the anode current of tube B will be strong enough to operate relay 1. Relay 1 in closing will close its contacts at 8 and open its back contacts at 6. Opening of the contacts at 6 will open the circuit from 1 through the operating coil C. Thus, if, upon the closing of switch S, the illumination of daylight is sufficient, depending upon the settings of P_1 and P_2, contactor C will not operate and the lights will remain off.

On the other hand, if, when switch S is closed, the illumination of the phototube is not sufficient to cause relay 1 to operate, then the thermal relay will operate after a short lapse of time and close its contacts I_1. Closing of contacts T_1 will short the heating element of the thermal relay, and the current through operating coil C will then be sufficient to operate contactor C. Contactor C in closing will close its contacts C_2 and C_3 and will open its contacts C_1. The circuit to the lamps is now closed, and the lamps will be lighted. The closing of contacts C_2 will short the thermal relay out of the circuit of the operating coil C of contactor C. Contactor C will be held closed as long as the illumination on the phototube is not sufficient to operate relay 1. Also the thermal relay will cool and reset itself.

When the light intensity on the phototube caused by daylight and the artificial lighting increases sufficiently, the anode current of tube B will be increased enough to cause relay 1 to operate. Closing of relay 1 will close its contacts at 8 and open its back contacts at 2. The heating element of the thermal relay is now connected in parallel with the operating coil C of contactor C. The heating element will eventually operate the thermal relay, closing its contacts T_1. Closing of contacts T_1 shorts the operating coil C of contactor C. Contactor C is no longer energized, and contacts C_2 and C_3 therefore open, while contacts C_1 close. Closing of C_1 alters the bias on the grid of tube B. The setting of P_2 should be such that the light intensity which caused the lights to be turned off will hold relay 1 closed, so that it will take the desired reduction of light intensity to reduce the anode current of tube B sufficiently so that it will

no longer hold relay 1 closed. After contactor C opens, there is no longer current through either operating coil C or the heating element of the thermal relay so long as relay 1 stays closed. The thermal relay therefore resets itself. After the lights have been turned off, should the light intensity on the phototube decrease momentarily to a value so that relay 1 opens, current will pass from point 1 to 2, to 6 through the heater element of the thermal relay to 3, through operating coil C to 4, through resistor R to 5, and back to the other side of the line at 7. The current through operating coil C will not be great enough, however, to operate contactor C, because of the resistance of the heating element of the thermal relay. Therefore, a momentary reduction of light intensity will not turn the lights on. If the reduction in light intensity persists, the thermal relay will function and close its contacts T_1. Closing of contacts T_1 will short the heating element of the thermal relay, and the current through operating coil C will be sufficient to close contactor C and turn the lights on.

68. Voltage Regulators.—Several different electronic circuits have been devised for automatically holding the output voltage of generators at a constant value. Such voltage-regulator circuits have been employed with both d-c and a-c generators. Since the average electrical worker will seldom come in contact with these electronic voltage regulators, a discussion of the circuits is not warranted in this book.

DIVISION 7

GENERATORS AND MOTORS

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PRINCIPLES, CHARACTERISTICS, AND MANAGEMENT OF D-C GENERATORS

1. Direct-current generators impress on the line a direct or continuous e.m.f.—one that is always in the same direction. Commercial d-c generators have commutators and may thereby be distinguished from a-c machines. The function of the commutator and the elementary ideas of generation of e.m.f. and of commutation are discussed in Div. 1. Additional information in regard to commutation as applied to d-c motors, which is in general true for d-c generators, is given hereinafter.

2. Excitation of Generator Fields.—To generate an e.m.f., conductors must cut a magnetic field which in commercial machines must be relatively strong. A permanent magnet can be used for producing such a field in a generator of small output, such as a telephone magneto or the magneto of a megger, but for generators for light and power the field is produced by electromagnets, which may be excited by the machine itself or "separately excited" from another source.

Self-excited machines may be of the series, shunt, or compound type depending upon the manner of connecting the field winding to the armature. In the series type of machine, the field winding (the winding which produces the magnetic field) is connected in series with the armature winding. In the shunt type, the field winding is connected in parallel, shunt, with the armature winding. Compound machines have two field windings on each pole. One of these windings is connected in series with the armature winding, and the other is connected in parallel or shunt with the armature winding.

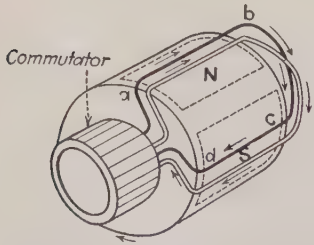


FIG. 1.—Two coils of a four-pole, lap-wound armature.

3. Armature windings of d-c machines may be of the lap or wave type. The difference in the two types is in the manner of connecting the armature coils to the commutator. A coil is the portion of the armature winding between successive connections to the commutator. In the lap type of winding (see Fig. 1) the two ends of a coil are connected to adjacent commutator segments. In the wave type of winding (see Fig. 2) the two ends of a coil are connected to commutator segments that are displaced from each other approximately 360 electrical degrees.

The type of armature winding employed affects the voltage and current capacity of the machine but has no effect upon the power capacity. This is due to the fact that the number of parallel paths between armature terminals is affected by the type of winding. For a wave-wound machine there are always two paths in parallel in the armature winding between armature terminals. For a lap-wound machine there are as many parallel paths in the armature winding as there are pairs of poles on the machine. For the same number and size of armature conductors a machine when wave connected would generate a voltage that would be equal to the voltage generated when lap connected times the number of pairs of poles. But the current capacity would be decreased in the same proportion that the voltage was increased. The current capacity when wave connected is therefore equal to the capacity when lap connected divided by the number of pairs of poles.

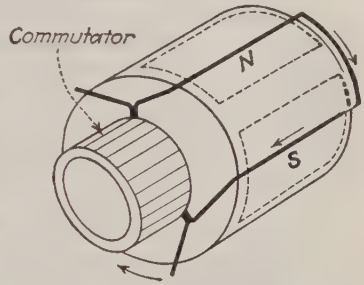


FIG. 2.—Coil on a four-pole wave-wound armature.

4. The value of the voltage generated by a d-c machine depends upon the armature winding, the speed, and the field current. For a given machine therefore the voltage generated can be controlled either through

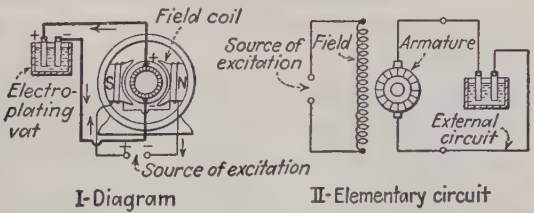


FIG. 3.—Separately excited generator.

adjusting the speed or the field current. Since generators are usually operated at constant speed, the voltage must be controlled by means of adjustment of the field current.

5. Separately excited d-c generators are used for electroplating and for other electrolytic work where it is essential that the polarity of a machine be not reversed. Self-excited machines may change their polarities. The essential diagrams are shown in Fig. 3. The fields may be excited from any d-c, constant-potential source, such as a storage battery or lighting circuit.

The field magnets can be wound for any voltage because they have no electrical connection with the armature. With a constant field excita-

tion, the voltage will drop slightly from no load to full load because of armature drop and armature reaction.

Separate excitation is advantageous when the voltage generated by the machine is not suitable for field excitation. This is true for especially low- or high-voltage machines.

6. Series-wound generators have their armature winding, field coils, and external circuit connected in series with each other so that the same current flows through all parts of the circuit (see Fig. 4). If a series generator is operated at no load (external circuit open), there will be no current through the field coils, and the only magnetic flux present in the machine will be that due to the residual magnetism which has been retained by the poles from previous operation. Therefore, the no-load voltage of a series generator will be only a few volts produced by cutting the residual flux. If the external circuit is closed and the current

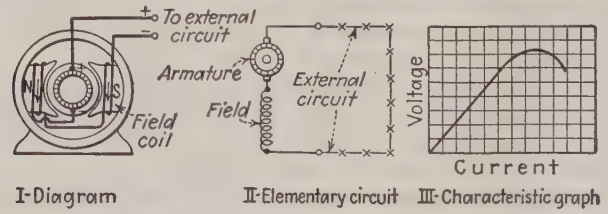


FIG. 4.—Series generator.

increased, the voltage will increase with the increase in current until the magnetic circuit becomes saturated. With any further increases of load the voltage will decrease.

Series generators are used sometimes in street-railway service. They are connected in series with long trolley feeders supplying sections of the system distant from the supply point, in order to boost the voltage. Series generators are also used for supplying the power for certain test work.

7. The shunt-wound generator is shown diagrammatically in Fig. 5, I, II. A small part of the total current, the exciting current, is shunted through the fields. The exciting current varies from possibly 5 per cent of the total current in small machines to 1 per cent in large ones. The exciting current is determined by the voltage at the brushes and the resistance of the field winding. Residual magnetism in the field cores permits a shunt generator to "build up." This small amount of magnetism that is retained in the field cores induces a voltage in the armature (Timbie, "Elements of Electricity"). This voltage sends a slight current through the field coils, which increases the magnetization. Thus, the induced voltage in the armature is increased. This in turn increases the current in the fields, which still further increases the magnetization, and so on, until the normal voltage of the machine is reached and conditions

are stable. This "building up" action is the same for any self-excited generator and often requires 20 to 30 sec.

If a shunt generator (Timbie) runs at constant speed, as more and more current is drawn from the generator, the voltage across the brushes falls slightly. This fall is due to the fact that it requires more and more

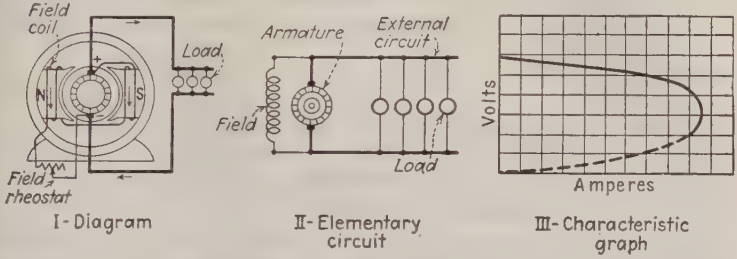


FIG. 5.—Shunt generator.

of the generated voltage to force this increasing current through the windings of the armature, *i.e.*, the armature *IR* drop increases. This leaves a smaller part of the total e.m.f. for brush e.m.f., and then, when the brush pressure falls, there is a slight decrease in the field current, which is determined by the brush pressure. This and armature reactions cause the total e.m.f. to drop a little, which still further lowers the brush potential. These causes combine to gradually lower the voltage, especially at heavy overloads. The curve in Fig. 5, III, shows these charac-

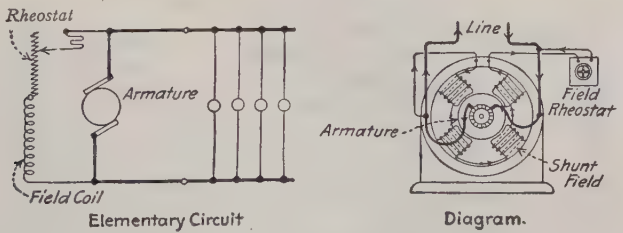


FIG. 6.—Shunt-wound generator with rheostat.

teristics. For small loads the curve is nearly horizontal, but at heavy overloads it shows a decided drop. The point where the voltage of a commercial machine drops off rapidly is beyond the operating range and is only of theoretical interest.

The voltage of a shunt machine may be kept fairly constant by providing extra resistance in the field circuit (see Fig. 6), which may be cut out as the brush potential falls. This will allow more current to flow through the field coils and increase the number of magnetic lines set up in the magnetic circuit. If the speed is kept constant, the armature conductors

cut through the stronger magnetic field at the same speed, and thus induce a greater e.m.f. and restore the brush potential to its former value. This resistance may be cut out either automatically or by hand (see Rheostat in the Index).

A shunt-wound generator gives a fairly constant voltage, even with varying loads, and can be used for incandescent lighting and other constant-potential loads. These generators will operate well in parallel,

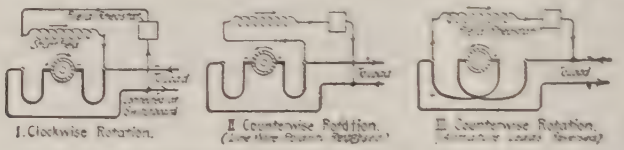


FIG. 7.—Changing rotation direction of shunt machine.

because the voltage of the machines decreases as the load increases. Shunt generators running in parallel will "divide the load" well between themselves if the machines have similar characteristics.

Shunt generators are now seldom used for general power and lighting service, having been superseded by compound-wound machines for this service. Shunt generators are employed for the charging of storage batteries, for applications requiring a constant voltage which is maintained by means of a voltage regulator controlling the shunt field current, and for exciters for supplying the d-c field current for a-c generators.

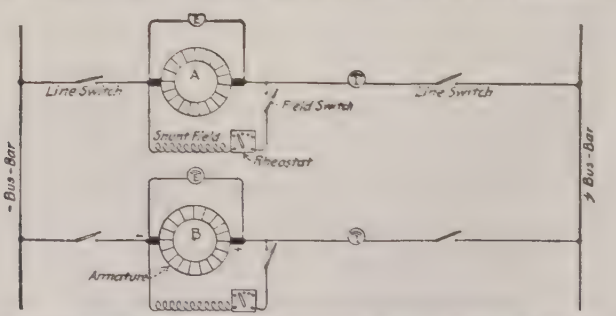


FIG. 8.—Connections for shunt generators for parallel operation.

The necessary change in connections when reversing the direction of rotation of a shunt-wound machine is indicated in Fig. 7. Rotation is **clockwise** when, facing the commutator end of a machine, the rotation is in the direction of the hands of a clock. **Counterclockwise** rotation is the reverse. It is necessary, when changing the direction of rotation, not to reverse the direction of current through the field windings. If it is reversed the magnetism developed by the windings on starting will oppose the residual magnetism and the machine will not "build up."

8. Parallel Operation of Shunt Generators.—As suggested in Sec. **7,** shunt-wound generators will in general operate very well in parallel and will divide the load well if the machines have similar characteristics. If the machines do not have similar characteristics, one machine will take more than its share of the load and may tend to drive the other as a motor. When it is running as a motor its direction of rotation will be the same as when it was generating, hence the operator must watch the ammeters closely for an indication of this trouble. Shunt generators are now seldom installed. Figure 8 shows the connections for shunt generators that are to be operated in parallel.

9. The compound-wound generator is shown diagrammatically in Fig. 9, I. If a series winding is added in a proper manner to a shunt

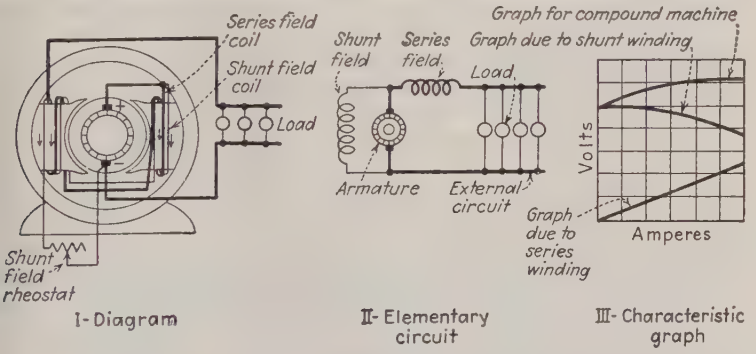


Fig. 9.—Compound generator.

generator (Fig. 5), the two windings will tend to maintain a constant voltage as the load increases. The magnetization due to the series windings increases as the line current increases, thus tending to increase the generated voltage. The drop of voltage at the brushes that occurs in a shunt generator may thus be compensated for.

It is necessary that the series winding be connected in such a manner that its current will aid that of the shunt-field winding in producing magnetic flux. With this proper connection, the machine is said to be cumulatively connected. If the series field is connected in the reverse manner so that the series field tends to produce flux in the opposite direction to that produced by the shunt field, the machine is said to be differentially connected. The differential connection of compound machines is used in some very special cases.

10. A flat-compounded generator is one having its series coils so proportioned that the voltage remains practically constant at all loads from 0 to 1¼ full load.

11. An overcompounded generator has its series windings so proportioned that its full-load voltage is greater than its no-load voltage.

Overcompounding is necessary where it is desirable to maintain a practically constant voltage at some point out on the line distant from the generator. It compensates for line drop. The characteristic curve (Fig. 9, III) indicates how the terminal voltage of a compound-wound machine is due to the action of both shunt and series windings. Generators are usually overcompounded so that the full-load voltage is from 5 to 10 per cent greater than the no-load voltage.

Although compound-wound generators are usually provided with a field rheostat, it is not intended for regulating voltage as the rheostat of a shunt-wound machine is. It is provided to permit initial adjustment of voltage and to compensate for changes of the resistance of the shunt winding caused by heating. With a compound-wound generator, the voltage having been once adjusted, the series coils automatically strengthen the magnetic field as the load increases. For d-c power and lighting work, compound-wound generators are used almost universally.

11A. An undercompound generator is one with a relatively weak series-field winding, so that the voltage decreases with increased load.

12. If a compound-wound generator is short-circuited, the field strength due to the series windings will be greatly increased, but the field due to the shunt winding will lose its strength. For the instant or so that the shunt magnetization is diminishing, a heavy current will flow. If the shunt magnetization is a considerable proportion of the total magnetization the current will decrease after the heavy rush and little harm will be done if the armature has successfully withstood the heavy rush. However, if the series magnetization is quite strong in proportion to the shunt, their combined effect may so magnetize the fields that the armature will be burned out.

13. A short-shunt, compound-wound generator has its shunt field connected directly across the brushes (see Fig. 9, II). Generators are usually connected in this way because it tends to maintain the shunt-field current more nearly constant on variable loads, as the drop in the series winding does not directly affect the voltage on the shunt field with this arrangement.

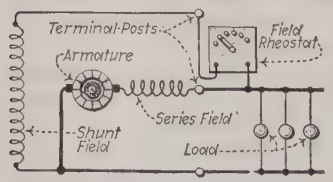


FIG. 10.—Long-shunt compound-wound generator.

14. A long-shunt generator has its shunt-field winding connected across the terminals of the generator (see Fig. 10).

15. Nearly all commercial d-c generators have more than two poles. A two-pole machine is a bipolar machine; one having more than two poles is a multipolar machine. Figure 11 shows the connections and the direction of the magnetic flux of a four-pole machine. Diagrams for machines having more poles would be similar. In multipolar machines there is usually one set of brushes for each pair of poles, but with wave-

wound armatures, such as are used for railway motors, one set of brushes may suffice for a multipolar machine. The connections of different makes of machines vary in detail, and the manufacturers will always furnish complete diagrams, so no attempt will be made to give them here. The directions of the field windings on generator frames are given in Fig. 12. The directions of the windings on machines having more than four poles are similar in general to those of the four-pole machines.

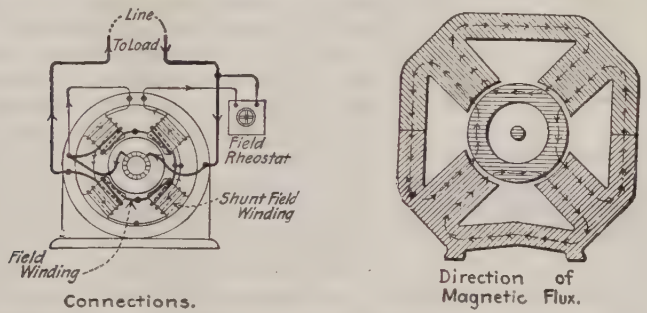


FIG. 11.—Diagrams for four-pole compound-wound generator.

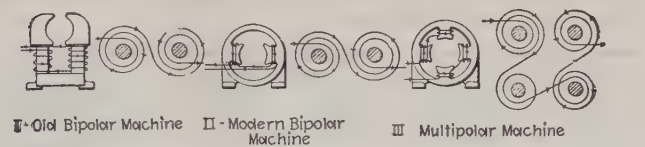


FIG. 12.—Direction of field windings on generator frames.

16. A series shunt for a compound generator consists of a low-resistance connection across the terminals of the series field (see Figs. 13 and 14) by means of which the compounding effect of the series winding may be regulated by shunting more or less of the armature current around the series coils. The shunting resistance may be in the form of grids, on large machines, or of ribbon resistors. In the latter case it is usually insulated and folded into small compass.

17. Parallel operation of compound-wound generators is readily effected if the machines are of the same make and voltage or are designed with similar electrical characteristics (Westinghouse Electric & Manufacturing Co.). The only change usually required is the addition of an equalizer connection between machines. If the generators have different compounding ratios it may be necessary to readjust the series-field shunts to obtain uniform conditions.

18. An equalizer, or equalizer connection, connects two or more generators operating in parallel at a point where the armature and series-field leads join (see Fig. 13), thus connecting the armatures in multiple

and the series coils in multiple, in order that the load will divide between the generators in proportion to their capacities. The arrangement of connections to a switchboard (Westinghouse Electric & Manufacturing Co.) is shown in Fig. 14. Consider, for example, two compound-wound machines operating in parallel without an equalizer. If, for some reason, there is a slight increase in the speed of one machine, it would take more than its share of load. The increased current flowing through its series field would strengthen the magnetism, raise the voltage, and cause the machine to carry a still greater amount until it carried the entire load. Where equalizers are used, the current flowing through each series coil is inversely proportional to the resistance of the series coil circuit and is independent of the load on any machine; consequently an increase of voltage on one machine builds up the voltage of the other at the same time, so that the first machine cannot take all the load but will continue to share it in proper proportion with the other generators.

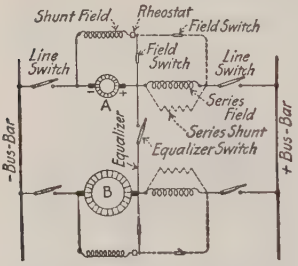


FIG. 13.—Elementary connections for parallel operation of compound-wound generators.

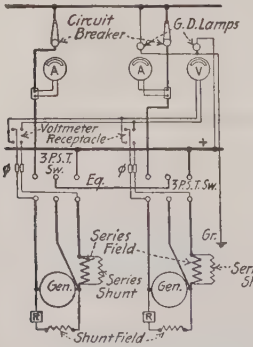


FIG. 14.—Diagram of connections of two compound-wound generators to switchboard. (*Westinghouse Electric & Manufacturing Co.*)

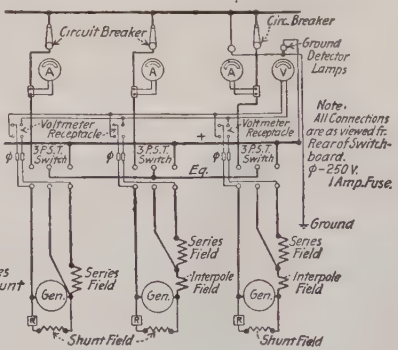


FIG. 15.—Diagram of connections of two direct-current commutating-pole generators in parallel with one generator without commutating poles.

19. Operation of a shunt and a compound dynamo in parallel is not successful because the compound machine will take more than its share of the load unless the shunt-machine field rheostat is adjusted at each change in load.

20. Connecting Leads for Compound Generators.—See that all the cables for machines of equal capacity that lead from the series fields of the various machines to the bus bars are of equal resistance. This means that if the machines are at different distances from the switchboard, different sizes of wire should be used, or resistance should be inserted in the low-resistance leads.

With generators of small capacity the equalizer is usually carried to the switchboard, as suggested in Figs. 14 and 15, but with larger ones it is carried under the floor directly between the machines (Fig. 16). The positive and the equalizer switch of each machine may be mounted side by side on a pedestal near the generator (Fig. 16). The difference in potential between the two switches is only that due to the small drop in the series coil. The positive bus bar is carried along under the floor near the machines. This permits leads of minimum length. Leads of equal lengths should be used for generators of equal capacities. If the capacities are unequal (see Sec. **24**) it may be necessary to loop the leads (see Fig. 16).

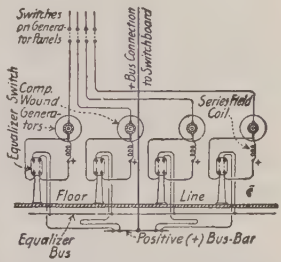


FIG. 16.—Equalizer carried directly between machines.

21. Ammeters and circuit breakers for compound generators should, as in Fig. 14, always be inserted in the lead not containing the compound winding. If the ammeters are put in the compound-winding lead the current indications will be inaccurate because current from this side of the machine can flow either through the equalizer or the compound-winding lead.

22. To Start a Shunt- or Compound-wound Generator.—(1) See that there is enough oil in the bearings, that the oil rings are working, and that all field resistance is cut in. (2) Start the prime mover slowly and permit it to come up to speed. See that the oil rings are working. (3) When machine is up to normal speed, cut out field resistance until voltage of the machine is normal or equal to or a trifle above that on the bus bars. (4) Throw on the load. If three separate switches are used, as in Fig. 13, close the equalizer switch first, the series coil line switch second, and the other line switch third. If a three-pole switch is used, as in Fig. 14, all three poles are, of course, closed at the same time. (5) Watch the voltmeter and ammeter and adjust the field rheostat until the machine takes its share of the load. A machine generating the higher voltage will take more than its share of the load, and if its voltage is too high it will run the other as a motor.

23. To Shut Down a Shunt- or Compound-wound Generator Operating in Parallel with Others.—(1) Reduce the load on the machine as much as possible by cutting resistance into the shunt-field circuit with the field

rheostat. (2) Throw off the load by opening the circuit breaker, if one is used, otherwise open the main generator switches. (3) Shut down the driving machine. (4) Wipe off all oil and dirt, clean the machine, and put it in good order for the next run. Turn all resistance in the field rheostat. Open the main switch.

24. To Adjust the Division of Load between Two Compound-wound Generators.—First adjust the series shunts of both machines so that, as nearly as possible, the voltages of both will be the same at one-fourth, one-half, three-fourths, and full load. Then connect the machines in parallel, as suggested in Fig. 13, for trial. If, upon loading, one machine takes more than its share of the load (amperes), increase the resistance of the path through its series-field coil path until the load divides between the machines proportionally to their capacities. Only a small increase in resistance is usually needed. The increase may be provided by inserting a longer conductor between the generator and the bus bar, or iron or german-silver washers can be inserted under a connection lug. Inasmuch as (when machines are connected in parallel) adjustment of the series-coil shunt affects both machines, nothing can be accomplished through making such adjustment.

25. Commutating-pole, D-c Generators.—Generators without commutating poles (Westinghouse Electric & Manufacturing Co.) which operate under severe overloads and over a wide speed range are apt to spark under the brushes at the extreme overloads and at the higher speeds. This is because the field due to the armature current distorts the main field to such an extent that the coils being commutated under the brush are no longer in a magnetic field of the proper direction and strength. To overcome this, commutating poles are placed between the main poles (see Fig. 17). These commutating poles introduce a magnetic field of such direction and strength as to maintain the magnetic field, at the point where the coils are commutated, at the proper strength for good commutation. Commutating poles are sometimes called interpoles. "Commutating poles" is a preferable term.

The winding on the commutating poles is connected in series with the armature so that the strength of the corrective field increases and decreases with the load. The adjustment and operation of commutating-pole generators is not materially different from that of noncommutating-pole machines.

When the brush position of a commutating-pole machine has once been properly fixed, no shifting is afterward required or should be made, and most commutating-pole generators are shipped without any shifting device. An arrangement for securely clamping the brush-holder rings to the field frame is provided.

In commutating-pole apparatus, accurate adjustment of the brush position is necessary. The correct brush position is on the no-load neutral point, which is located by the manufacturer. A template is

furnished with each machine, or some other provision is made whereby the brush location can be determined in the field. If the brushes are given a backward lead on a commutating-pole generator, the machine

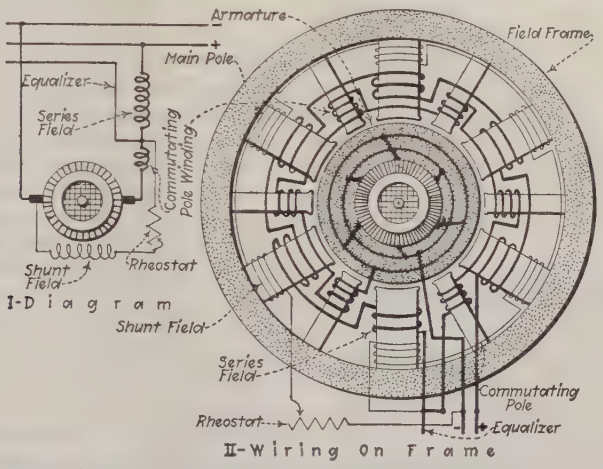


FIG. 17.—Diagram of compound-wound commutating-pole machine.

will overcompound and will not commutate properly. With a forward lead of the brushes, a generator will undercompound and will not commutate properly.

26. The object in using the commutating pole is to produce within the armature coil under commutation an e.m.f. of the proper value and direction to reverse the current in the coil while it is yet under the brush—a result that is essential to perfect commutation. The variation in the flux distribution in the air gap of a commercial d-c machine of the ordinary shunt-wound type, at no load and under full load, is shown in Fig. 18. Consider now the value and position of the flux in the coil under the brush when the machine is operating at full load. The motion of the armature through this flux causes the generation within the coil of an e.m.f., and the sign of this e.m.f. is such as to tend to cause the current in the coil to continue in the direction which it had before the coil reached the brush, and hence it opposes the desired reversal of the current before the coil leaves the brush.

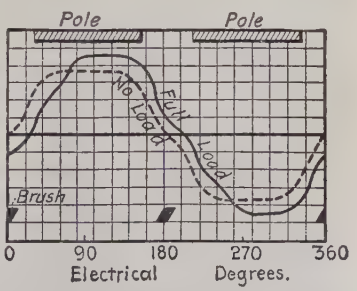


FIG. 18.—Distribution of magnetic flux at no load and at full load, without commutating poles.

There is an additional detrimental influence which tends to retard the rapid reversal of the current even when all other influences are absent. This latter influence is due to the local magnetizing effect of the current in the coil under the brush. On account of this the lines of force which surround the conductor change in value with the fluctuations of the current as it tends to be reversed. This generates in the coil an e.m.f. which opposes the change in the value of the current. This reactive e.m.f. is in the same direction as that due to the cutting of the flux by the coil under the brush and is likewise proportional to the speed.

It will be apparent that even were the field distortion completely neutralized, the detrimental reactive e.m.f. would yet remain. The improved and practically perfect commutation of the commutating-pole machine is due to the fact that the flux, which is locally superposed upon the main field, not only counterbalances the undesirable main flux cut by the coil under the brush, but it causes to be generated within the coil an e.m.f. sufficient to equal and oppose the reactive e.m.f. just referred to. This effect will be appreciated from a study of Fig. 19, which represents the distorted flux of the motor of the usual design, as shown in Fig. 18, and indicates the results to be expected when the flux due to the auxiliary or commutating pole is given the relatively proper value.

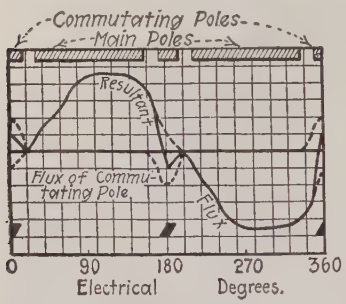


FIG. 19.—Distribution of magnetic flux at full load, with and without commutating poles.

It is worthy of note that this desirable effect is the more pronounced the weaker the main field; and that the commutation voltage, if correct for a low speed, is correct for a high speed; and that with increase of load-current and main-field distortion there is a proportional increase of countermagnetizing field produced in the coil under the brush, up to the point of magnetic saturation of the auxiliary pole; and that sparkless operation is ensured for all operating ranges both of speed and load.

27. The action of the magnetic flux in a commutating-pole generator is illustrated in Fig. 20. The direction of the main field flux is shown by the dashed line. The direction of the armature magnetization is shown by the dotted lines. The direction of the flux in the commutating pole is shown by the full line. It is evident that the commutating-pole flux is in a direction opposite to that of the armature flux, and as the commutating-pole coil is more powerful at the commutating point in its magnetizing action than the armature coils, the flux of the armature coils is neutralized. With a less powerful magnetizing force from the commutating pole than from the armature at the commutating point, the

armature would overpower the commutating pole and reverse the direction of the flux, which would result in a bad commutating condition.

28. To Determine the Neutral Point of a Motor or Generator (Fig. 21).—Two copper-wire contact points, or contactors, C are inserted in an insulating block and are allowed to extend through it about $\frac{1}{16}$ in. The distance between the centers of the points should be equal to the width of one commutator bar. The contactors are connected to a millivoltmeter V, which should, preferably, be of the differential type. Place both points on the commutator while the machine is being rotated with the brushes lifted from the commutator and the shunt field is being excited. While shifting the points around the periphery of the commutator, hold the block so that an imaginary line connecting the two contact points will be perpendicular to the axis of the commutator.

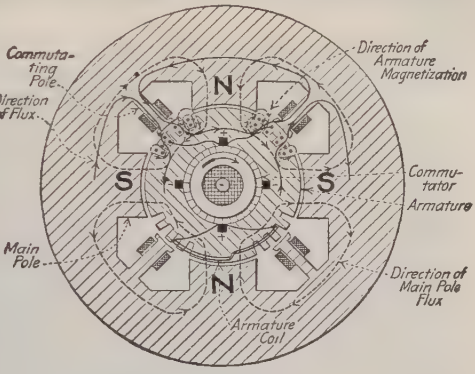


FIG. 20.—Distribution of flux in a commutating-pole generator.

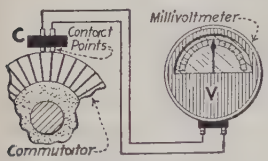


FIG. 21.—Connections for determination of the neutral point.

If a differential voltmeter is used, its needle will indicate either to the right or to the left of the zero point until the contacts are exactly over the neutral position; then the voltmeter will read zero. The brushes may now be shifted so that an imaginary line, parallel to the axis of the commutator and bisecting the bearing surface of the brush, will coincide with a point equidistant between the two contact points.

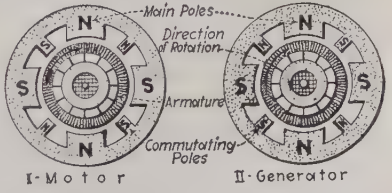


FIG. 22.—Diagram showing polarity of commutating poles. (Clockwise rotation.)

29. To Determine the Proper Polarity of the Commutating Poles.—For a **motor**: proceeding from pole to pole around the frame in the direction of armature rotation, each commutating pole should have the same polarity as the main pole which just precedes it (Fig. 22, I).

For a **generator:** proceeding from pole to pole around the frame, in the direction of armature rotation, each commutating pole should have a polarity opposite to that of the main pole which just precedes it (Fig. 22, II).

30. Commutating-pole machines will run in parallel with each other and with noncommutating-pole machines, provided correct connections are made. See illustrations. The series-field windings on commutating-pole machines are usually less powerful than on noncommutating-pole machines; and particular attention should, therefore, be paid to getting the proper drop in accordance with instructions of Sec. **24.** A connection diagram in shown in Fig. 15.

30A. Compensating Field Windings.—The commutating poles of a d-c motor or generator do not neutralize the effect of the armature current upon the flux of the machine. They simply produce a local flux at the commutating location of the armature conductors. For machines that must operate under very severe operating conditions of overload and speed range, it is necessary for satisfactory operation that means be provided to neutralize the tendency of the armature current to distort and change the flux of the machine. This neutralization is produced by means of an additional winding called a compensating field winding. A compensating field winding consists of coils embedded in slots in the pole faces of the machine, as shown in Figs. 22*A* and 22*B*. The compensating winding is connected in series with the armature in such a manner that the current through the individual conductors of the compensating field winding will be opposite to the direction of the corresponding armature conductors, as shown in Fig. 22*A*.

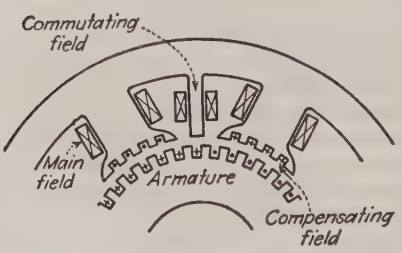


FIG. 22*A*.—Section of a d-c machine showing location of compensating field winding.

31. Three-wire, d-c generators are ordinary d-c generators with the modifications and additions described below. They are usually wound for 125/250-volt, three-wire circuits. In commercial three-wire generators (Westinghouse Electric & Manufacturing Co.), four equidistant taps are made in the armature winding, and each pair of taps diametrically opposite each other is connected together through a balance coil. These balance coils may be external (Fig. 23) or wound within the armature. The middle points of the two balance coils (see Index) are connected together, and this junction constitutes the neutral point to which the third or neutral wire of the system is connected. A constant voltage is maintained between the neutral and outside wires which, within narrow

limits, is one-half the generator voltage. The generator shaft is extended at the commutator end for the collector rings. Four collector brushes and brush holders are used in addition to the regular d-c brushes and brush holders.

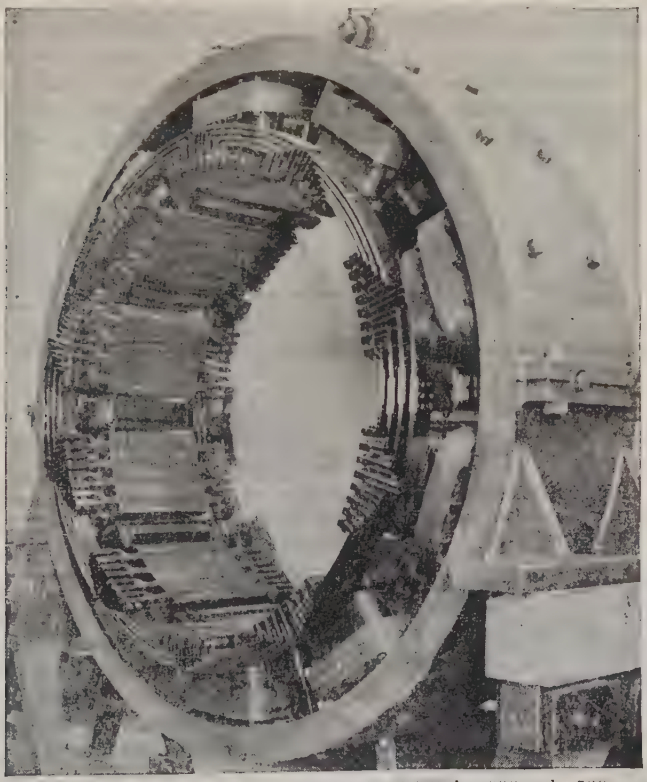


FIG. 22*B*.—Frame and field structure of a 2,000-hp 600-volt 500-rpm d-c motor showing compensating windings in the faces of the main poles. (*Courtesy of Westinghouse Electric & Manufacturing Co.*)

32. The series coils of compound-wound, three-wire generators are divided into halves (see Fig. 23), one of which is connected to the positive and one to the negative side. This is done to obtain compounding on either side of the system when operating on an unbalanced load. To understand this, consider a generator with the series field in the negative side only and with most of the load on the positive side of the system. The current flows from the positive brush through the load and back along the neutral wire without passing through the series field. The generator is then operating as an ordinary shunt machine. If most of

the load is on the negative side, the current flows out the neutral wire and back through the series fields, boosting the voltage the maximum amount. Such operation is evidently not satisfactory, and so the divided series fields are provided.

33. Switchboard Connections for Three-wire Generators.—Figure 24 is a diagrammatical representation of the switchboard connections for two three-wire generators operated in multiple (Westinghouse publication). Two ammeters indicate the unbalanced load. The positive lead and equalizer are controlled by a double-pole circuit breaker; the negative lead and equalizer likewise. Note that both the positive and

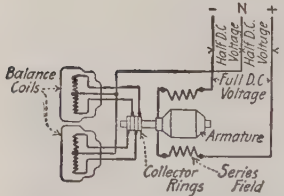


FIG. 23.—Diagram showing connections for three-wire generator.

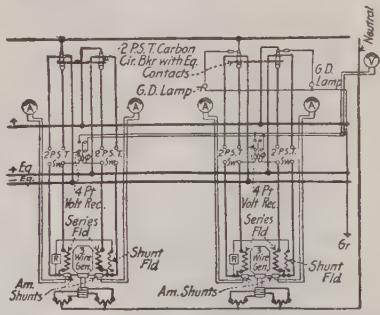


FIG. 24.—Diagram of connections of two three-wire d-c generators operating in parallel, 125–250 volts.

negative equalizer connections as well as both the positive and negative leads are run to the circuit breakers in addition to the main switches on the switchboard. It is necessary that this be done in all cases. Otherwise, when two or more machines are running in multiple and the breaker comes out, opening the main circuit to one of them but not breaking its equalizer leads, its ammeter is left connected to the equalizer bus bars and current is fed into it from the other machines through the equalizer leads, either driving it as a motor or destroying the armature winding (see also Figs. 25 and 26).

34. As there are two series fields, two equalizer busses are required when several three-wire machines are installed (see Fig. 24) and are to be operated in parallel. The two equalizers serve to distribute the load equally between the machines and to prevent crosscurrents due to differences in voltage on the different generators. Because of the equalizer connections, two small terminal boards are supplied, one for each side of the generator. Arrangement is also made for ammeter shunts on the terminal boards.

An ammeter shunt is mounted directly on each of the contact boards of the machine. The total current output of the machine can thereby be read at the switchboard. As the shunts are at the machine, there is

no chance for current to leak across between generator switchboard leads without causing a reading on the ammeters. Two ammeters must be provided for reading the current in the outside wires. It is important that the current be measured on both sides of the system, for with an ammeter in one side of the system only, it is possible for a large unmeasured current to flow in the other side with disastrous results.

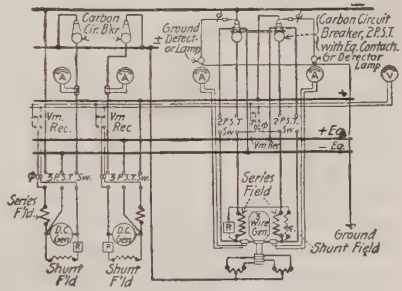


FIG. 25.—One three-wire d-c generator, 125–250 volts, in parallel with two two-wire generators, 125 volts. Diagram of connections.

35. Wires connecting the balance coils to a three-wire generator must be short and of low resistance. Any considerable resistance in these will affect the voltage regulation. The unbalanced current flows along these connections; consequently, if they have much resistance, the resulting drop in voltage reduces the voltage on the heavily loaded side.

Switches are ordinarily not placed in the circuits connecting the four collector rings to the balance coils. When necessary, the coils may be disconnected from the generator by raising the brushes from the collector rings. Switching arrangements often make it necessary to run the balance-coil connections to the switchboard and back, requiring heavy leads to keep the drop low; or if heavy leads are not used, then poor regulation may result. The balance coils are so constructed that there is very little likelihood of anything happening to them that will not be taken care of by the main circuit breakers. Complete switchboard connection diagrams are given in Figs. 24, 25, and 26.

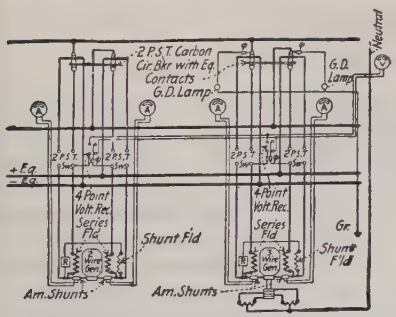


FIG. 26.—One three-wire d-c generator, 125–250 volts, in parallel with one two-wire generator, 250 volts. Diagram of connections.

36. Commutating-pole, Three-wire Generators.—On three-wire generators, connections are so made that one-half of the commutating-pole winding is in the positive side and the other half is in the negative side. This ensures proper action of the commutating pole at unbalanced load (see Figs. 24, 25, and 26 and the text accompanying them).

37. Three-wire, direct-current generators can be operated in parallel (Westinghouse publication) with each other and in parallel with other

machines on the three-wire system (see Figs. 24, 25, and 26). When operating a three-wire, 250-volt generator in multiple with two-wire, 125-volt generators, the series fields of the two two-wire generators must be connected, one in the positive side and one in the negative side of the system, and an equalizer must be run to each machine. Similarly, when operating a three-wire, 250-volt generator in multiple with a 250-volt, two-wire generator, the series field of the 250-volt, two-wire generator must be divided and one-half connected to each outside wire. The method of doing this is to disconnect the connectors between the series-field coils and reconnect these coils so that all the N pole fields will be in series on one side of the three-wire system and all the S pole fields in series on the other side of the system.

38. Testing for Polarity.—When a machine that is to operate in parallel with others is connected to the bus bars for the first time it should

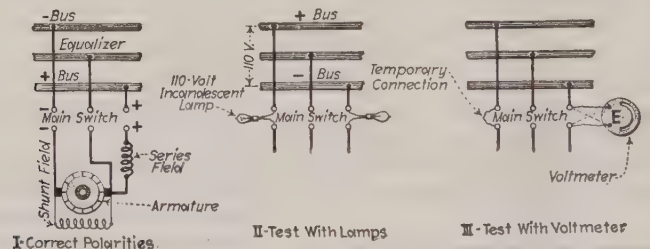


FIG. 27.—Tests for polarity.

be tested for polarity. The + lead of the machine should connect to the + bus bar and the − lead to the − bus bar (Fig. 27, I). The machine to be tested should be brought up to normal voltage but not connected to the bars. The test can be made with two lamps (Fig. 27, II), each lamp of the voltage of the circuit. Each is temporarily connected between a machine terminal and bus terminal of the main switch. If the lamps do not burn, the polarity of the new machine is correct, but if they burn brightly its polarity is incorrect and should be reversed. A voltmeter can be used (Fig. 27, III). A temporary connection is made across one pair of outside terminals, and the voltmeter is connected across the other pair. No deflection or a small deflection indicates correct polarity. (Test with voltmeter leads one way and then reverse them, as indicated by the dotted lines.) A full-scale deflection indicates incorrect polarity. Use a voltmeter having a voltage range equal to twice the voltage on the bus bars.

39. Third-brush generators are widely used on automobiles for providing the necessary electric power for the charging of the storage battery and operation of lights. If an ordinary generator were employed for this purpose the voltage would vary over a wide range as the speed of the car

changed. The voltage would vary nearly proportionally to the speed. This, of course, would not be satisfactory either for the proper charging of the battery or for operation of the car lights. The third-brush generator is a special shunt generator with the field winding connected between one of the main brushes and the auxiliary or third brush (see Fig. 28). As the speed of the automobile increases, thereby increasing the speed of the generator, the voltage tends to increase. This increase in voltage increases the current delivered by the generator. But the increase in current so changes the magnetic-flux distribution in the machine that the voltage between the third brush and main brush A is reduced. This

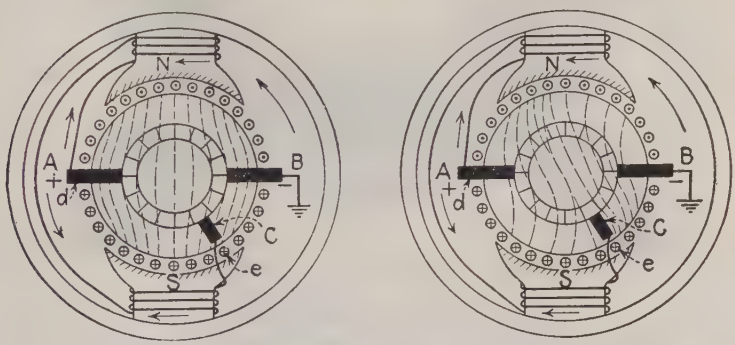
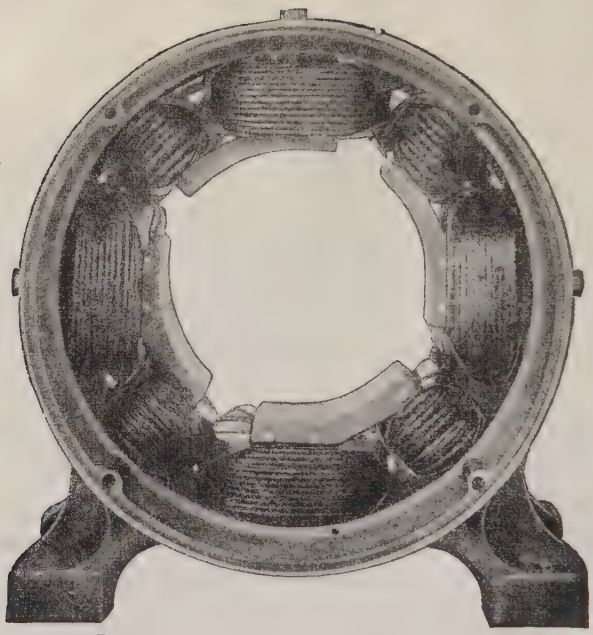


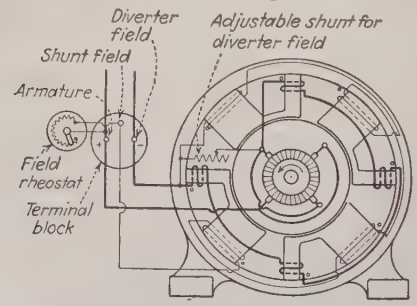
FIG. 28.—Third-brush generator. (*From Dawes, "Electrical Engineering—Direct Currents."*)

reduces the field current and therefore flux of the machine and tends to bring the main voltage between brushes A and C back to its former value. This action does not maintain absolutely constant voltage for different speeds, but the voltage is held within certain limits so that an excessive voltage is not developed at high speeds which would overcharge the battery and shorten the life of the lamps.

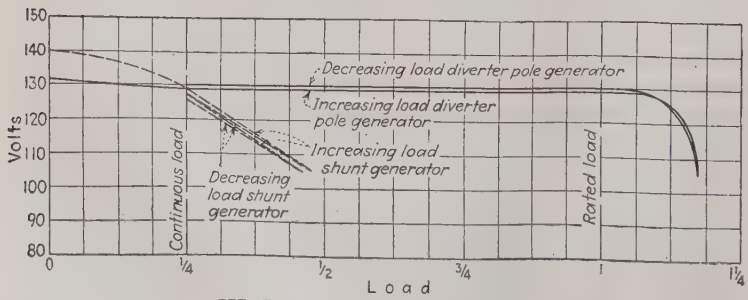
40. Diverter-pole generators are a special type of d-c generator (developed by the Electric Products Co.) that have particular advantages for the charging of batteries by the floating method of charge. The machine is constructed with additional pole pieces (the diverter poles) located midway between the main poles in the same manner as commutating poles. Each main pole is connected by a magnetic bridge to one diverter pole. The windings of the main poles are connected in shunt with the armature winding, and the windings of the diverter poles in series with the armature winding. The construction, connections, and load-voltage characteristics for such a generator are shown in Fig. 29. These generators will produce an almost constant terminal voltage from no load to 110 per cent of rated load. Above 110 per cent of rated load the voltage drops very rapidly.



I. Frame and field-winding construction.



II. Diagram of connections.



III. Load-voltage characteristic.

FIG. 29.—Diverter-pole generator. (*Electric Products Co.*)

At no load, a part of the magnetic flux resulting from the shunt coil on the main pole piece is diverted and does not pass through the armature.

As the load increases, the series winding on the diverter pole rediverts this flux to the armature and provides a commutating field.

By proper proportioning of the shunt and series windings, the flux in the armature varies with the load so as to compensate for the IR drop in the generator and for speed changes of the driving motor.

A flat voltage curve is obtained, since the necessary magnetic changes produced by the series winding take place only in the diverter pole, the flux from the main pole remaining constant. The flux densities in the diverter pole are kept low so that the magnetic changes which occur in this part of the magnetic circuit take place on the straight portion of the magnetization curve, thus eliminating most of the curvature from the voltage characteristic.

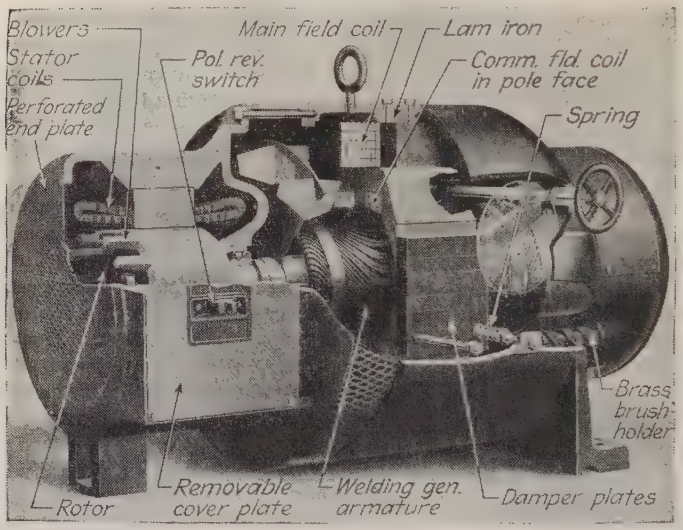
By correct adjustment of the diverter-pole winding, by means of an adjustable shunt, a very straight flat curve is obtained with only a very slight rise on approaching zero load.

At some value of the load current the ampere turns on the diverter pole will equal those on the main pole, and, at this time, the magnetic flux leaking across the bridge to the diverter pole is all rediverted across the air gap; hence there is no further leakage flux for an increased current to redivert to the armature.

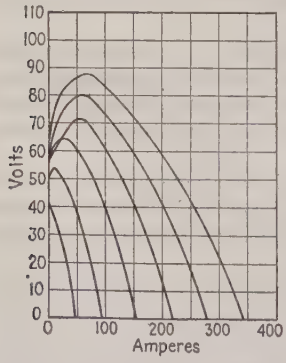
When the load is increased beyond this point, the increased ampere turns on the diverter pole combine with the armature cross-magnetizing force to send magnetic flux in the reverse direction across the leakage bridge, which tends to demagnetize the main pole and reduce the generator voltage.

Good commutation is assured, as the diverter pole provides a commutating field of the correct direction for improving commutation, and this field varies with the current output just as in a commutating-pole generator.

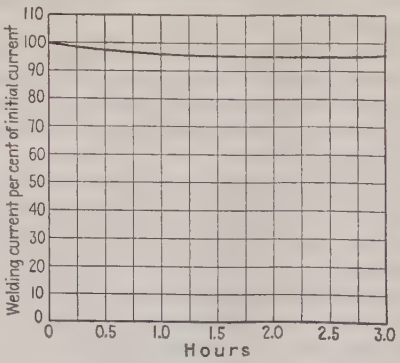
41. Flexarc generators (Fig. 30) are special series generators manufactured by the Westinghouse Electric & Manufacturing Co. for supplying the energy for electric welding. The pole tips are connected by means of iron leakage or damper plates. These plates form a good magnetic path for the magnetomotive force of the armature to act upon and thus increase the armature reaction effect of the armature current. The welding current is regulated by the position of the damper plates with respect to the poles. The position of the plates is controlled by means of a handwheel. A pointer connected to the handwheel shaft is fitted with a dial, called the pre-act dial. The dial is calibrated in amperes so that the operator can adjust the handwheel for any desired welding current before he starts welding. Typical voltage-current characteristics for one of these welding generators are shown in Fig. 30, II. Each curve is the characteristic for a certain setting of the handwheel. The variation of



I. Cut-away view of the Flexarc welder.



II.



III.

FIG. 30.—Flexarc welding generator. (II) Characteristic curve of 200-amp. Flexarc welder, gas-engine driven. (III) Curve showing variation of welding current as set warms up after starting cold. No adjustments of current control during test. Voltage constant at 40 volts.

welding current from cold starting to hot condition is very small, as shown in Fig. 30, III. With these generators there is no shunt field, and therefore no field rheostat or exciter is required for their control. They also eliminate the use of an external reactor for the limitation of current surges.

41A. Control generators are specially designed d-c generators which are employed for the precise automatic control of d-c motors. They are used for performing a wide variety of functions, such as:

1. Controlling and regulating speed, voltage, current, or power accurately over a wide range.

2. Controlling tension and torque to maintain product uniformity in winding, drawing, and other similar operations.

3. Speeding up acceleration or deceleration to increase the production of high-inertia machines, etc.

Small motors may be supplied directly with power from the control generator. In the majority of applications, however, the capacity of the control generator is not sufficient to supply the motor directly, and the control generator energizes the field of a main generator which supplies the motor with power. A control generator must possess the characteristics of moderately fast response and low power consumption from the activating control circuit. The application of control generators for motor control is discussed in more detail in Sec. **140C.**

41B. The amplidyne is a control generator manufactured by the General Electric Co. The construction of the amplidyne, as shown in Fig. 30*A*, differs from the conventional d-c generator in the following ways:

1. Separately excited field windings (up to four individual windings) with only a small number of ampere-turns in each winding. The field windings are called control fields or control windings.

2. Brushes (*A* and *B* in Fig. 30*A*) located in the conventional neutral position are short-circuited on each other.

3. Pole structure split in two.

4. Addition of a second set of brushes (*C* and *D* in Fig. 30*A*) located 90 electrical degrees from the conventional neutral position. These brushes are the load brushes of the machine and are connected to the output terminals of the machine.

5. A compensating field winding wound around the pole structure of the machine instead of being located in slots on the face of the poles. The compensating field winding is connected in series with the load brush circuit.

The amplidyne functions in the following manner: When a control-field winding or windings are energized, a magnetic flux will be produced in paths *G* and *H* of Fig. 30*A*. The rotation of the armature through this flux will generate voltage in the armature conductors. However, because of the small number of ampere-turns in the control-field windings,

the voltage generated from brush B to brush A will produce only a reasonable value of current in the short-circuited armature. The direction of this short-circuited armature current will be as shown by the designations inside the conductors in Fig. 30A. The short-circuited armature current will produce magnetic flux in the paths E and F. Voltages will be induced in the armature conductors by this flux E and F. These conductor voltages will produce no net voltage from brush B to A, since the voltages in conductors from B to C and B to D will just neutralize the voltages produced in the conductors from C to A and D to A.

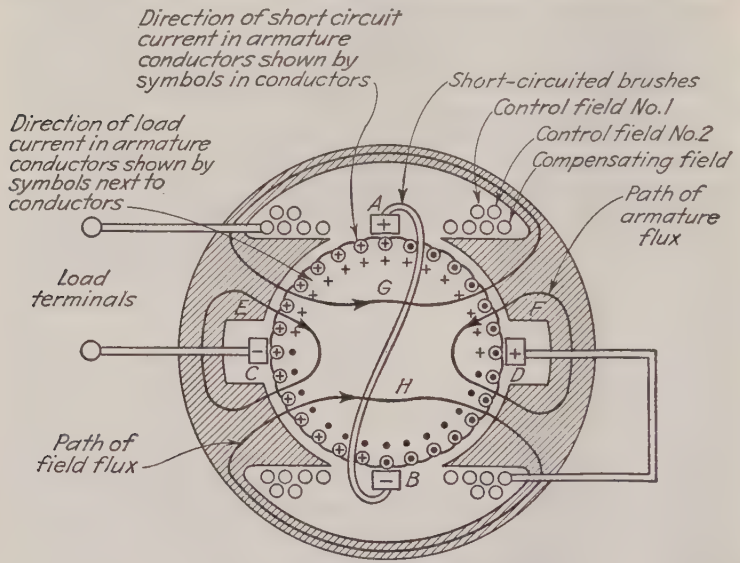


FIG. 30A.—Cross section of amplidyne generator.

respectively. A voltage will be produced, however, from brush C to brush D. Since brushes C and D are connected to the terminals of the machine, an output voltage will be produced whenever a control-field winding is energized. When brushes C and D are connected to an external load circuit, current will flow through the armature conductors, because of the load current, in the directions designated in Fig. 30A by the markings alongside each conductor. The actual current through each individual armature conductor will be the combination of the armature short-circuit current in paths B to A and the armature load current in paths C to D. The load current in the armature should not materially affect the flux of the machine. Therefore, a compensating field winding is connected in series with the load. This winding is so located and designed that its ampere-turns will practically neutralize the

ampere-turns produced by the armature load current. The functioning of the machine is summarized as follows:

1. Excitation of a control-field winding produces flux G and H.
2. Flux G and H produces no net voltage between brushes C and D but does produce net voltage in armature paths BCA and BDA.
3. Voltage in paths BCA and BDA produces current in armature because of short circuit AB.
4. Short-circuit current in armature produces flux E and F.
5. Flux E and F produces no net voltage between brushes A and B but does produce net voltage between brushes C and D. This is the load or output voltage of the machine.
6. Voltage CD produces load current in armature and external circuit.
7. Ampere-turns (flux-producing tendency) of load armature current are neutralized by ampere-turns of compensating field winding.

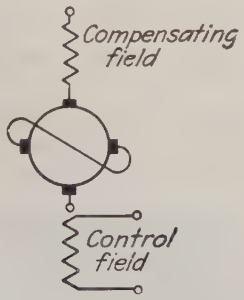


FIG. 30*B*.—Basic symbol for amplidyne.

Thus the control-field current controls the short-circuit armature current, which in turn controls the output voltage. Since the control-field winding is designed with very small watt capacity, a very small change of input power to a control-field winding will produce a large change in output power.

The symbolic representation of an amplidyne generator as used in wiring diagrams is shown in FIG. 30*B*.

41C. The rototrol is the trade name of the control generator made by the Westinghouse Electric & Manufacturing Co. The rototrol is essentially a small d-c generator similar in electrical and mechanical construction to a standard d-c generator of equal size, except that the rototrol is provided with a number of field windings. The voltage output of the machine depends entirely upon the control of and the interaction of these field windings. The rototrol is provided with a self-energizing field winding and two or more control-field windings (see FIG. 30*C*). The self-energizing field winding is generally connected in series with the rototrol armature and furnishes the necessary excitation for the

normal operation of the machine. All the other field windings are called control-field windings. The control-field windings are used to measure and compare standard and actual values representative of the quantity to

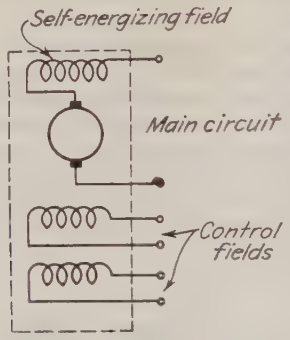


FIG. 30C.—Basic symbol for rototrol.

be regulated. One of the control-field windings is called a pattern-field winding, and the others are called pilot-field windings. The pattern field is the control field, which is separately excited from an independent

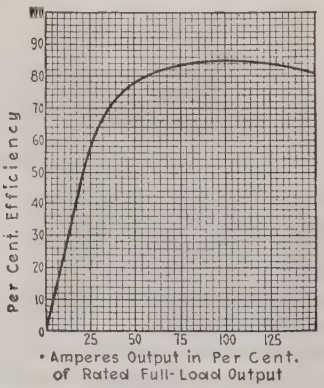


FIG. 31.—Efficiency graph of a 10-kw. compound-wound d-c generator.

source and is used as a calibration, or standard of comparison. The pilot fields are the remainder of the control-field windings, which measure directly or indirectly the quantity to be regulated.

42. The efficiency of a d-c generator increases with the load up to a certain point. Figure 31 indicates typical efficiency performances.

Large-capacity machines have higher full-load efficiencies than small ones. Generators should be selected of such capacity that they will, in so far as possible, operate at loads in the neighborhood of their normal ratings.

43. Approximate Data on Standard, Compound-wound, D-c, Commutating-pole Generators

The efficiency of a generator depends on its design, and, to a certain extent, on its speed and voltage. Average values are given in the following table that are fairly representative of modern practice.

Capacity, kw.	Output current, amp.			Efficiency, per cent		
	125 volts	250 volts	500 volts	½ load	¾ load	Full load
5	40	20	10	77.0	81.0	82.5
10	80	40	20	82.0	85.0	86.0
15	120	60	30	82.5	86.5	86.5
20	160	80	40	84.0	86.5	87.5
25	200	100	50	85.0	88.0	89.0
35	280	140	70	87.0	89.0	89.5
50	400	200	100	88.0	89.5	90.5
60	480	240	120	88.5	90.5	91.0
75	600	300	150	88.5	90.5	91.0
90	720	360	180	88.5	90.5	91.0
100	800	400	200	89.0	90.5	91.0
125	1,000	500	250	90.5	91.0	91.0
150	1,200	600	300	90.5	91.3	91.5
200	1,600	800	400	91.0	91.5	92.0
300	2,400	1,200	600	91.3	91.8	92.0
400	3,200	1,600	800	91.8	92.3	92.5
500	4,000	2,000	1,000	91.8	92.2	92.5
750	6,000	3,000	1,500	92.0	92.3	92.5
1,000	8,000	4,000	2,000	92.5	93.0	93.5

44. Rating of D-c Generators.—The standard methods of rating generators are as follows:

Continuous Rating.—A generator given a continuous power-output rating will carry its rated load continuously in an ambient temperature of 40°C. without exceeding a specified rise in temperature. Generators rated on a 40°C. rise basis will carry 115 per cent of their rated load continuously without injury to themselves, provided that the service conditions are normal. The factor of 1.15 is known as a service factor.

Nominal Rating.—A generator given a nominal power-output rating will carry 50 per cent overload for a period of 2 hr. without injury to itself.

Continuous with 2-hr. 25 Per Cent Overload Rating.—A generator rated on this basis in addition to carrying its rated power load continuously will carry 25 per cent overload for a period of 2 hr. without injury to itself.

45. Brushes, Their Adjustment and Care (Westinghouse Instruction Book).—The position of the brushes on a d-c generator should be on or near the no-load neutral point of the commutator. This neutral point on most standard, noncommutating-pole generators is in line with the center of the pole, and the brushes should be set a little in advance of this neutral point. The brushes of noncommutating-pole generators should

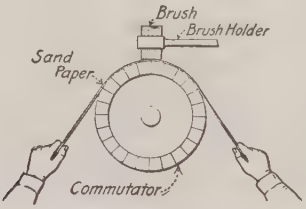


FIG. 32.—Sandpapering brushes.

be given a slight "forward lead" in the direction of rotation of the armature. Motor brushes should be set somewhat back of the neutral point, the "backward lead" in this case being approximately equal to the forward lead on generators. The exact position in either case is that which gives the best commutation at normal voltage for all loads. In no case should the brushes be set far enough from the neutral point to cause dangerous sparking at no load. For commutating-pole machines it is essential that the brushes be located at the neutral point.

The ends of all brushes should be fitted to the commutator so that they make good contact over their entire bearing faces. This can be most easily accomplished after the brush holders have been adjusted and the brushes inserted as follows: Lift a set of brushes sufficiently to permit a sheet of sandpaper to be inserted. Draw the sandpaper in one direction only, preferably in the direction of rotation, under the brushes (Fig. 32) being careful to keep the ends of the paper as close to the commutator surface as possible and thus avoid rounding the edges of the brushes, each set of brushes being similarly treated in turn. Start with coarse and finish with fine sandpaper. With copper-plated brushes, bevel their edges slightly, so that the copper will not touch the commutator.

46. Operating Instructions.—Do not lubricate the commutator with oil; a piece of muslin moistened with vaseline may be used to clean and lubricate the commutator.

Emery is a conductor and should not be used in fitting brushes or cleaning the commutator; use sandpaper or sandstone (Sec. **77**) and do not use it on the commutator too frequently.

Do not use greater brush tension than necessary; tension greater than 2 lb. per sq. in. is seldom required. When replacing brushes, use the quality and size originally supplied with the machine, and fit them to the commutator with sandpaper before use (Sec. **45**). Do not open generator-field circuits quickly; open the switch slowly, permitting the arc to extinguish gradually, which should take about 5 sec.

47. Direct-current Generator and Motor Defects

(From *Machinery*, by special permission)

TROUBLES OF D-C MOTORS AND GENERATORS—THEIR LOCALIZATION AND CORRECTION

Sparking at the brushes	Faults of			
	Brushes	Not set diametrically opposite	*A.* Should have been set properly at first, by counting bars, or by measurement on the commutator *B.* Can be done if necessary while running; move rocker until brush on one side sparks least, then adjust other brushes so they do not spark	1
		Not set at neutral points	Move rocker back and forth slowly until sparking stops	2
		Not properly trimmed	*A.* Brushes should be properly trimmed before starting. If there are two or more brushes one may be removed and retrimmed *B* Clean with alcohol or ether, then grind and reset carefully (see 1, 4, 38)	3
		Not in line	Adjust each brush until bearing is on line and square on commutator bar, bearing evenly the whole width (see 12 *A*)	4
		Not in good contact	*A.* Clean commutator of oil and grit. See that brushes touch *B.* Adjust tension screws and springs to secure light, firm and even contact (see 38 *B*)	5
	Commutator	Rough; worn in grooves or ridges; out of round	*A.* Grind with fine sandpaper on curved block, and polish with crocus cloth. Never use emery in any form *B.* If too bad to grind down turn off true in a lathe or preferably in its own bearings, with a light tool and rest, a light cut; running slowly NOTE.—Armature should have $\frac{1}{16}$ to $\frac{1}{8}$ in. end motion when running, to wear commutator evenly and smoothly (see 31)	6 7
		High bars	Set "high bar" down carefully with mallet or block of wood, then clamp end nuts tightly, or file, grind, or turn true. A high bar may cause singing (see line 38)	8
		Low bars	Grind or turn commutator true to the surface of the low bars	9
		Weak magnetic field	*A.* Broken circuit } in field coils { repair if external *B.* Short circuit } in field coils { rewind if internal *C.* Machine not properly wound, or without proper amount of iron—no remedy but to rebuild it	10
	Armature	Short-circuited coils	*A.* Remove copper dust, solder, or other metallic contact between commutator bars *B.* See that clamping rings are perfectly free, and insulated from commutator bars; no copper dust, carbonized oil, etc., to cause an electrical leak *C* Test for cross connection or short circuit, and if such is found rewind armature to correct. *D.* See that brush holders are perfectly insulated. No copper dust, carbon dust, oil or dust, to cause an electrical leak (see 1, 2, 60)	11

Sparking at the brushes	Armature faults	Broken coils		*A.* Bridge the break temporarily by staggering the brushes, until machine can be shut down (to save bad sparking) and then repair *B.* Shut down machine if possible, and repair loose or broken connection to commutator bar *C.* If coil is broken inside, rewinding is the only sure remedy. May be temporarily repaired by connecting to next coil, across mica *D* Solder commutator lugs together, or put in a "jumper," and cut out, and leave open the broken coil. Be careful not to short-circuit a good coil in doing this (see 11)	12
		Cross connections		Cross connections may have same effect as short circuit, treat as such (see 11). Each coil should test complete without cross and no ground	13
	Excessive current in armature	Generator	Excessive load	*A.* Reduce number of lamps and load	14
			Ground and leak from short circuit on line	*B.* Test out, locate, and repair	
			Dead short circuit on line	*C.* NOTE.—Dead short circuit will or should blow safety fuse. Shut down, locate fault, and repair before starting again and put in a new fuse	
		Motor	Excessive voltage	*D.* Use proper current only, and with proper rheostat and controller and switch	
			Excessive amperes on constant-current circuit	*E.* See that controller, etc., are suitable with ample resistance	
			Friction	*F.* See that there is no undue friction or mechanical resistance anywhere (see 3 *B* and 35, 36)	
			Too great load on pulley	*G.* Reduce load on motor to its rated capacity or less	
Heating of parts	Armature	Overloaded		Overload. Too many amperes, lights, or too much power being taken from machine (see 11, 12, 13, 14)	15
		Short circuit		Short-circuited generally dirt, etc., at commutator bars (see 11, 12, 13, 14)	16
		Broken circuit		Broken circuit often caused by a loose or broken band (see 11, 12, 13, 14)	17
		Cross connection		Cross connection. Often caused by a loose coil abrading on another coil or core (see 11, 12, 13, 14)	18
		Moisture in coils		Dry out by gentle heat. May be done by sending a small current through, or causing machine to generate a small current itself, by running slowly	19

Direct-current Generator and Motor Defects (*Continued*)

Heating of parts	Armature	Eddy currents in core		Iron of armature hotter than coils after a run. Faulty construction. Core should be made of finely laminated insulated sheets. No remedy but to rebuild	20
		Friction		Hot boxes or journals may affect armature (see 23, 33)	21
	Field coils	Excessive current	Shunt	*A.* Decrease voltage at terminals by reducing speed. Increase field resistance by winding on more wire, or finer wire or putting resistance in series with fields	22
			Series	*B.* Decrease current through fields by shunt, removing some of field winding or rewind with coarser wire	
				NOTE.—Excessive current may be from a short circuit, or from moisture in coils, causing a leakage (see 10, 24)	
		Eddy currents		Pole pieces hotter than coils after short run, due to faulty construction, or fluctuating current, if latter, regulate, and steady current	23
		Moisture in coils		Coils show less than normal resistance, may cause short circuit or body contact to iron of dynamo. Dry out as in 19 (see also 22, note)	24
	Bearings	Not sufficient or poor oil		*A.* See that plenty of good mineral oil, filtered clean and free from grit, feeds but be careful that it does not get on commutator or brush holder (see 11) *B.* Cylinder oil or vaseline may be used if necessary to complete run, mixed with sulphur or white lead, or hydrate of potash. Then clean up and put in good order	25
		Dirt or grit in bearings		*A.* Wash out grit with oil while running, then clean up and put in order. Be careful about flooding commutator and brush holder *B.* Remove caps and clean and polish journals and bearings perfectly, then replace. See that all parts are free and lubricate well *C.* When shut down, if hot, remove bearings and let them cool naturally; then clean, scrape and polish, and assemble; see that all parts are free, and lubricate well	26
		Rough journals or bearings		Smooth and polish in a lathe, removing all burrs, scratches, tool marks, etc., and rebabbitt old boxes and fit new ones	27
		Journals too tight in bearings; bent shaft		Slacken cap bolts, put in liners, and retighten till run is over, then scrape, ream, etc., as may be needed or bend or turn true in lathe or grinder. Possibly a new box or shaft will be needed	28 29
		Bearings out of line		Loosen bearing bolts, line up and block, until armature is in center of pole pieces, ream out dowel and boltholes and secure in new position	30

Heating of parts	Bearings	End pressure of pulley hub or shaft collars	*A.* See that foundation is level and armature has free end motion *B.* If there is no end motion, file or turn ends of boxes or shoulders on shaft to provide end motion *C.* Then line up shaft and belt, so that there is no end thrust on shaft, but that the armature plays freely endways when running	31
		Belt too tight	*A* Reduce load so that belt may be loosened and yet not slip. Avoid vertical belts if possible *B.* Choose larger pulleys, wider and longer belts with slack side on top. Vibrating and flapping belts cause winking lamps	32
		Armature out of center of pole pieces	*A.* Bearings may be worn out and need replacing, throwing armature out of center (see 36) *B.* Center armature in polar space, and adjust bearings to suit (see 30) *C.* File out polar space to give equal space all round *D.* Spring pole away from armature; this may be difficult or impossible in large machines	33
Noises		Armature or pulley out of balance	Faulty construction, armature and pulley should have been balanced when made. May be helped by balancing on knife-edges now	34
		Armature strikes or rubs pole pieces	*A.* Bend or press down any projecting wires, and secure with tie bands. *B.* File out pole pieces where armature strikes (see 30, 33)	35
		Collars or shoulders on shaft strike or rub box	Bearings may be loose or worn out. Perhaps new bearings are needed (see 30, 31)	36
		Loose bolt connection or screws	See that all bolts and screws are tight, and examine daily to keep them so	37
		Brushes sing or hiss	*A.* Apply stearic acid (adamantine) candle, vaseline, or cylinder oil to commutator and wipe off; only a trace should be applied *B.* Move brushes in and out of holder to get a firm smooth, gentle pressure, free from hum or buzz (see 3, 6, 7, 8, 9, 31)	38
		Flapping of belt	Use an endless belt if possible; if a laced belt must be used, have square ends neatly laced	39
		Slipping of belt from overload	Tighten belt or reduce load (see 32)	40
		Humming of armature lugs or teeth	*A.* Slope end of pole piece so that armature does not pass edges all at once *B.* Decrease magnetism of field, or increase magnetic capacity of tooth	41

Direct-current Generator and Motor Defects (*Continued*)

Speed	Runs too fast			Engine fails to regulate with varying load	Adjust governor of engine to regulate properly, from no load to full load, or get a better engine	42
				Series motor, too much current, and runs away	*A.* Series motor on constant current: (1) put in a shunt and regulate to proper current; (2) use regulator or governor to control magnetism of field for varying load *B.* Series motor on constant potential: (1) insert resistance and reduce current; (2) use a proper regulator or controlling switch; (3) change to automatic speed-regulating motor	43
	Runs too fast	Shunt motor		Field rheostat not properly set Not proper current Motor not properly proportioned	*A.* Adjust field rheostat to control motor *B.* Use current of proper voltage and no other, with a proper rheostat *C.* Get a better motor, one properly designed for the work	44
	Runs too slow			45, Engine fails to regulate. 46, Overload. 47, Short-circuit in armature. 48, Striking or rubbing of armature. 49, Friction. 50, Weak magnetic field.	45, same as 42; 46 see 14 *A*; 47, short circuit in armature (see 11); 48 rubbing armature (see 35); 49, friction (see 3 *B*); 50, weak magnetic field (see 10)	45 to 50
Motor	Stop or fail to start			Great overload (see 14 *F* and *G*)	Open switch and find and repair trouble. Keep switch open and rheostat "off" to see if everything is right	51
				Excessive friction (see 25, 33, 35)	Shunt motor on constant-potential circuit, fuse may blow or armature burn out	52
		Circuit open		Fuse melted or switch open Broken wire or connection Brushes not in contact Current fails or is shut off at station	*A.* Find and repair trouble after opening switch, then put in fuse (see 14 *C*) *B.* Open switch, find and repair trouble (see 12) *C.* Open switch and adjust (see 5) *D.* Open switch and return starting-box lever to off position, wait for current	53
				Short circuit of field	Test for and repair if possible. Examine insulation of binding posts and brush holders	54
				Short circuit of armature Short circuit of switch	Poor insulation, dirt, oil, and copper, or carbon dust often result in a short circuit	56
				Runs backward. Wrong connections	Connect correctly as per diagram; if no diagram is at hand, reverse connections to brushes or others until direction of rotation is satisfactory	57

Dynamo or generator	Reversed residual magnetism	Reversed current through field coils Reversed connections Earth's magnetism Proximity of another dynamo Brushes not in right position (see 1, 2, 3)	*A.* Use current from another machine or a battery through field in proper direction to correct fault. Test polarity with a compass *B.* If connections or winding are not known, try one way and test; if not correct reverse connections, try again and test *C.* Connect as per diagram for desired rotation, see that connections to shunt and series coils are properly made (see 57) *D.* Shift brushes until they operate better (see 1, 2, 3)	58
	Too weak residual magnetism		Same as 58 *A*	59
	Short circuit in machine		See 11, 54, 56	60
	Short circuit in external circuit		A lamp socket, etc., may be short-circuited or grounded, and prevent building up shunt or compound machines. Find and remedy before closing switch (see 54, 56)	61
	Field coils opposed to each other		Reverse connections of one of field coils and test. Find polarity with compass; if necessary try 58 *A*, *C*, *D*. If necessary reverse connections and recharge in opposite directions	62
	Open circuit	Broken wire Faulty connections Brushes not in contact Safety fuses melted or broken Switch open External circuit open	*A.* Search out and repair (see 12) *B.* Search out and repair (see 37) *C.* Search out and repair (see 5) *D.* Search out and repair (see 53 *A*) *E.* Search out and repair (see 53 *D*) *F.* Search out and repair with dynamo switch open until repairs are completed	63
	Too great load on dynamo		Reduce load to pilot lamp on shunt and incandescent machines; after voltage is obtained close switches in succession slowly, and regulate voltage (see 14 *A* and 65)	64
	Too great resistance in field rheostat		Bring up to voltage gradually with rheostat, and watch pilot lamp; regulate carefully	65

48. When starting, a generator may fail to excite itself (Westinghouse Instruction Book).—This may occur even when the generator operated perfectly during the preceding run. It will generally be found that this trouble is caused by a loose connection or break in the field circuit, by poor contact at the brushes due to a dirty commutator or perhaps to a loss of residual magnetism, or by incorrect position of brushes. Examine all connections; try a temporarily increased pressure on the brushes; look for a broken or burned-out resistance coil in the rheostat. An open circuit in the field winding may sometimes be traced with the aid of a magneto bell; but this is not an infallible test, as some magnetos will not ring through a circuit of such high resistance and reactance even though it is intact. If no open circuit is found in the rheostat or in the field

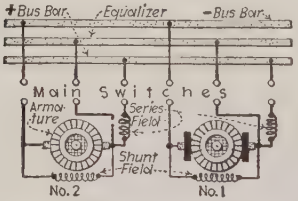


FIG. 33.—Exciting a generator.

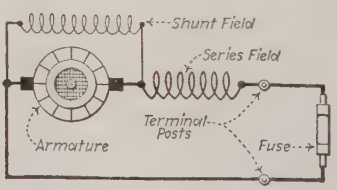


FIG. 34.—Another method of exciting a generator.

winding, the trouble is probably in the armature. But if it is found that nothing is wrong with the connections or the winding it may be necessary to excite the field from another generator or some other outside source.

Calling the generator we desire to excite "1," and the other machine from which current is to be taken "2," this procedure should be followed. Open all switches and remove all brushes from generator 1; connect the positive brush holder of generator 1 with the positive brush holder of generator 2; also connect the negative holders of the machines together (it is desirable to complete the circuit through a switch having a fuse of about 5 amp. capacity in series). Close the switch. Where the generator in trouble connects to bus bars fed by other generators, the same result can be effected by insulating the brushes of the machine in trouble from their commutator and closing the main switch (see Fig. 33). If the shunt winding of generator 1 is all right, its field will show considerable magnetism. If possible, reduce the voltage of generator 2 before opening the exciting circuit; then break the connections. If this cannot be done, throw in all the rheostat resistance of generator 1; then open the switch very slowly, lengthening out the arc which will be formed until it breaks.

A simple means for getting a compound-wound machine to pick up is to short-circuit it through a fuse having approximately the current capacity of the generator (see Fig. 34). If sufficient current to melt this

fuse is not generated, it is evident that there is something wrong with the armature, either a short circuit or an open circuit. If, however, the fuse has blown, make one more attempt to get the machine to excite itself. If it does not pick up, it is evident that something is wrong with the shunt winding or connections.

If a new machine refuses to excite and the connections seem to be all right, reverse the connections of the shunt field, *i.e.*, connect the wire which leads from the positive brush to the negative brush and the wire which leads from the negative brush to the positive brush. If this change of connections does no good, change back and locate the fault as previously suggested.

49. The proper connections for a shunt motor are as shown in Fig. 35. The field *B* is connected as shown, so that when the switch *D* is closed it

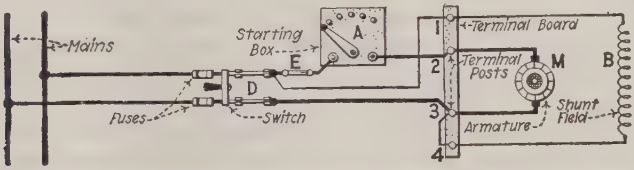


FIG. 35.—Control apparatus connections for a shunt motor.

becomes excited before the armature circuit through the switch *E* is closed. Thus when the motor armature has current admitted to it through switch *E* and starting resistance box *A*, the field is already on, and the full torque of the motor is obtained. The torque of a motor is equal to the product of a constant, the flux per pole, the ampere turns on the armature, and the number of poles. Hence, if the full field is not on the motor at starting, full torque will not be obtained.

50. If a motor will not start when the starting box is operated and when current is flowing in the armature, an investigation should be made to see if field flux is present, which can be done by holding a piece of iron, such as a key, against the pole piece. If the flux exists, the key will be drawn strongly against the pole piece; if there is no flux there will be practically no attraction.

51. Reversed Field-spool Connection.—There may be cases where the manufacturer has shipped a motor with one or more field spools reversed. If such is the case, no torque, or, perhaps, very weak torque, will be noticed. Under such conditions a trial with an iron key will indicate the presence of field magnetism, yet the weakness or total absence of torque will be present, and a trial of polarity should be made.

52. Running in the Wrong Direction.—Sometimes a motor when set up and started will run in the wrong direction. The only change necessary is to reverse the field connection. Thus Fig. 36, I, shows the connection for one direction of rotation and Fig. 36, II, that for the other.

Note that in Fig. 36, I, the brushes are shifted backward against the direction of rotation. For the opposite rotation, a backward lead, as shown in Fig. 36, II, must be chosen.

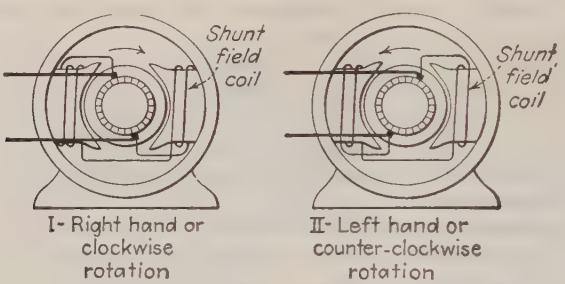


FIG. 36.—Connections for shunt-wound motors.

53. Testing Polarity of Field.—This can be done in two ways: First, by using a compass, bringing it near the various poles and noting the direction of the deflection of the needle. Since in all motors the poles alternate in magnetic polarity, in one pole the magnetism coming out and in the next going in, it follows that a certain end of a compass needle will point toward one pole and away from the next when conditions are normal. If, however, two adjacent poles show similar magnetism, the trouble is located, and the offending spool should be reversed. This should be done "end for end," not by turning on the axis. The latter operation does not change the direction of magnetism, while the former does. Direction of magnetism is determined by the following rule:

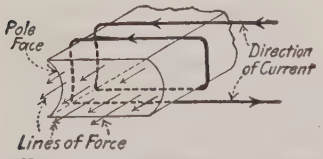


FIG. 37.—Direction of magnetism and current about a pole.

"Looking at the face of an electromagnet (such as the field spool of a motor), a pole will be north if the current is flowing around it in a direction opposite to the motion of the hands of a watch," (Fig. 37) and south if in the same direction as the motion of the hands of a watch (see also the rules outlined in Div. 1).

Another method of determining whether the magnetism of the poles is correct is to use two ordinary nails, their lengths depending upon the distance between pole tips. The point of one nail should touch one pole tip, the point of the other nail the other pole tip, and the heads of nails should touch each other.

When the current flows around the field spools, the polarity between any two poles is properly related if the nails placed as suggested stick together by the magnetism. If there is no tendency to stick, the polarity of the two poles is alike and therefore wrong.

54. Open Field Circuit.—If, on closing the field switch, no magnetism is obtained by trial with an iron key, as suggested above, there is an open circuit within one of the spools or in the wires leading to these spools. The open circuit can be located by shunting out one spool at a time and allowing current to flow through the rest until the defective spool is discovered. On a two-pole motor try first one spool and then the other. For a very short time, say, 10 min., double voltage can be carried on a spool. On a motor having four or more poles, three spools can always be left in circuit during the open-circuit investigations.

55. A method of locating an open-circuited field coil is illustrated in Fig. 38. Connect one terminal of the voltmeter to one side of the field-coil circuit and, with the bared end of a wire or a contactor, successively touch the junctions of the field-coil leads around the frame. When the open coil is bridged the voltmeter will show a full deflection. Another way follows: Connect the field-coil circuit terminals to a source of voltage. Connect the voltmeter successively across each coil as indicated by the dotted lines in Fig. 38. There will be no deflection on the voltmeter until the open coil is bridged, when the full voltage of the circuit will be indicated.

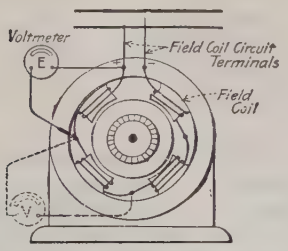


FIG. 38.—Locating field-coil troubles.

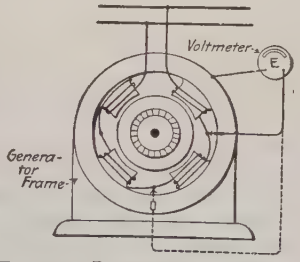


FIG. 39.—Locating grounded coil.

56. A grounded field coil can be located (Fig. 39) by connecting a source of voltage to the machine terminals, having first raised the brushes from the commutator, if it is a d-c machine. Connect one terminal of the voltmeter to the frame and the other to a lead with a bared end. Tap exposed parts of the field circuit with the bared end of the lead. The voltmeter deflection will be least near the grounded coil.

57. Heating of Field Coils (Westinghouse Instruction Book).—Heating of field coils may develop from any of the following causes: (1) too low speed; (2) too high voltage; (3) too great forward or backward lead of brushes; (4) partial short circuit of one coil; and (5) overload.

58. Direct-current armatures can be tested for the common troubles with the arrangement of Fig. 40. Terminals *b* and *c* are clamped to the commutator at points displaced 180 electrical degrees from each other and connected with a source of steady current through an adjustable

resistance and an ammeter. For a two-pole machine the terminals b and c will be located at opposite sides of the commutator. The terminals of a low-reading voltmeter (a galvanometer can often be used) are connected to two bare metal points, which are separated, by a distance equal to the width of one commutator segment plus the width of one mica strip, by an insulating block j. In use, the current is adjusted to produce a convenient deflection of the voltmeter when each of the points rests on an adjacent bar. The points are moved around the commutator and bridged across the insulation between every two bars. If the voltmeter deflection is the same for every pair of bars it indicates that there is no trouble in the armature.

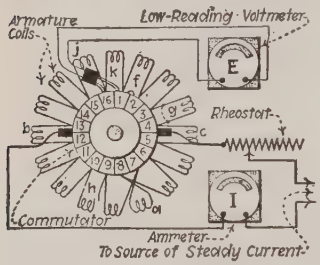


FIG. 40.—Method of testing an armature.

59. Sparking Due to Open Armature Circuit.—A cause of a sparking commutator is an open circuit in the winding, either in the armature body or, more often, where the lead from the armature winding is soldered to the commutator. In the latter case resoldering is a ready remedy. If, however, the location of the point of open circuit cannot be found, the bars can be bridged over on the commutator itself by fastening with solder, or otherwise, a strip of copper around the segments which indicate the break.

The indication of this trouble is very apparent, for, if an open circuit exists, the long heavy spark which accompanies it soon eats away the mica between the two segments which are on each side of the break. This shows positively where to bridge over. An open circuit also shows itself, when the machine is running, by the viciousness of the spark. It is unlike any other kind of commutator sparking, being heavy, long, and destructive in its action.

60. A poor connection between a bar and coil leads will cause a considerable deflection of the voltmeter (Fig. 40) when one of the points rests on the bar in trouble and the other rests on either of the adjacent bars.

61. An open-circuited coil, as h, Fig. 40, will prevent the flow of current through its half of the armature. There will be no deflection on that half of the armature until the "open" is bridged. Then the voltage of the testing circuit will be indicated.

62. Tests for Open Armature Circuits.—Another method (Fig. 41) is to apply to the commutator, at two opposite points, a low voltage, say from a battery or a dynamo with its voltage kept low. Place an ammeter in circuit and clean the surface of the commutator so that it is bright and smooth.

The terminal ends leading the current into and out of the commutator should be small, so that each rests only on a single segment (Fig. 41). Note the ammeter reading and rotate the armature slowly. At the point where the open circuit exists the ammeter needle will go to zero if the leads to the commutator bar have become entirely open-circuited. This is because the segment is attached to the winding through the commutator leads.

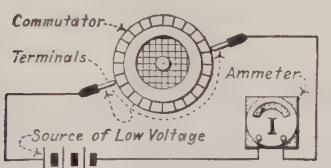


FIG. 41.—Testing for armature open circuit with an ammeter.

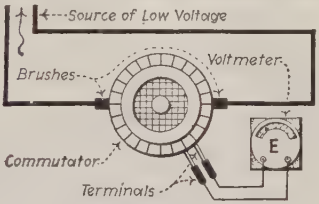


FIG. 42.—Testing for armature open circuit with a voltmeter.

If the armature does not show the above symptoms, try connecting a low-reading voltmeter or a galvanometer to two adjacent segments while the current is passing through the armature as described from some external low-voltage source (Fig. 42). Note the deflection. Pass from segment to segment in this manner, recording the drop between the successive pairs of bars. This drop, if the current is held constant from the external source, should be the same between each pair of adjacent segments. If any pair shows a higher drop than the others near it, a higher resistance connection exists there, perhaps causing sparking and biting of commutator insulation, to a less degree, to be sure, than with an actual open circuit, but enough, perhaps, to cause the trouble requiring the investigation.

63. The test for armature short circuits may be made as indicated in Fig. 42. It is called a bar-to-bar test. It is most valuable in locating faults in armatures. It is the method to use if a short circuit from one segment to another is suspected. When the section in which the short circuit, or partial short circuit, exists comes under the contacts, a low or perhaps no deflection is shown on the galvanometer or voltmeter, thus locating the defective place. Such short circuits, if they occur when running, owing to defective insulation, burn out the coil short-circuited. When the coil passes through the active field in front of the pole piece, an immense current is induced in it, causing a destruction of the insulation. When this occurs the coil should be open-circuited and bridged over, as suggested in a preceding paragraph, until a new coil can be inserted.

64. If two bars or a coil is short-circuited as at *f* or *g*, Fig. 40, respectively, there will be little or no voltmeter deflection when the two bars connecting to the "short circuit" are bridged by the points.

65. A grounded armature coil can be detected in the same manner as indicated in Fig. 39 for a field coil. Impress a low voltage on the terminals clamped to the commutator. Ground one side of the voltmeter on the shaft or spider and touch a lead connected to the other side to all the bars in succession. The minimum deflection will obtain when the bars connecting to the grounded coil are touched.

66. Crossed coil leads as at *a* (Fig. 40) are indicated by a twice normal deflection when the points bridge the bars 6 and 7 to which the crossed coils should rightly connect. The crossing of the coil leads connects two coils in series between the adjacent commutator segments and, hence, causes twice normal drop.

67. Reversed Armature Coil.—Instead of the armature winding progressing uniformly around from bar to bar of the commutator, there may at some point be a coil connected in backward. Such a reversed coil often causes bad sparking. One way to locate such a trouble is to pass a current through the armature, at opposite points on the commutator. Then with a compass explore around the armature the direction of magnetism from slot to slot. If a coil is reversed when the compass comes before it, the needle will reverse, giving a very definite indication of the improperly connected coil.

68. Heating of Armature (Westinghouse Instruction Book).—Excessive heating of the armature may develop from any of the following causes: (1) too great a load, (2) a partial short circuit of two coils heating the two particular coils affected and (3) short circuits or grounds on armature or commutator.

69. Hot Armature Coils.—Sometimes when a new machine is started, local heating occurs in the armature, following the exact shape of the armature coil. This may be because, in receiving its final turning off, the commutator bars were bridged with copper from one segment to another by the action of the turning tool. An examination of the commutator surface will reveal this bridging. When it is removed, satisfactory operation will ensue if the trouble has not gone too far and seriously injured the insulation of the coil.

70. Care of Commutators.—They should be kept smooth by the occasional use of No. 00 sandpaper. A small quantity of vaseline should be used as a lubricant. The lubricant should be applied to high-voltage generators by aid of a piece of cloth attached to the end of a dry stick. If the commutator gets "out of true" it should be turned down (refer to Sec. **77**). Inspect the commutator surface carefully to see that the copper has not been burned over from segment to segment in the mica and remove by a scrapper any particles of copper which may be found embedded in the mica. Keep oil away from the mica end rings of the commutator, as oily mica will soon burn out and ground the machine.

71. Process of Commutation and Correction of Glowing and Pitting.—The path of the current is as shown in Fig. 43. *A* is the carbon brush;

C, C', C'' are the commutator segments; B, B', B'' are the windings of the armature. At the position shown, coil B is short-circuited by the carbon, the current passing into the face of the brush and out again as shown by the dotted line. This local current may be many times larger than the normal flow of current and is the one that causes pitting.

With perfect commutation, with no sparking or glowing, there should be created in the short-circuited coil under the brush, by means of the flux from that pole tip away from which the armature is revolving, an e.m.f. This should be just large enough to reverse the current within the short-circuited coil and to render it equal to the current in the winding proper. Since on one side of the brush the current is in one direction and on the other side in the other direction, the act of commutation beneath the brush is to reverse this current and bring it up to the correct amount in the opposite direction.

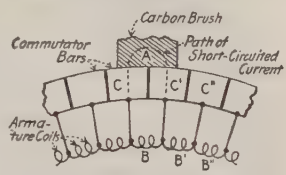


FIG. 43.—Armature coil short-circuited when commutating.

With copper brushes this reversal of current must be very accurately effected. With carbon brushes there is a much smaller tendency to spark, hence they will stand a certain inexactness of commutation adjustment. Experiments indicate that the carbon can resist as much as 3 volts creating current in the wrong direction and still not spark or glow. This is the property that has caused the use of carbon brushes instead of copper on most apparatus. When, however, this potential, induced in the wrong direction, rises above 3 volts during the passage of the armature coil underneath the brush, trouble from sparking and glowing occurs.

This is the reason that, in a motor, the brushes are pulled backward as far as possible at no load, so that the coil short-circuited by the brush may enter the fringe or flux from the pole tip, thus creating the proper reversal of current during the time the coil is passing under the brush. Since adjacent poles are opposite in polarity, only one can provide the proper flux direction for this reversal. In a motor it is always the pole behind the brush, and thus the brush requires a backward lead. In a generator it is the pole ahead of the brush in the direction of rotation. Hence generators require a forward lead.

If the motor gives trouble from glowing and pitting, the cause is probably this induced current, and the remedy is, first, to see that the lead of the brushes brings them in the most satisfactory position. If no change of lead or brush position can be found which will eliminate the trouble, the width of the brush must be changed. The wider the brush, the longer the coil suffers short circuit, as described. Conversely, the narrower the brush, the sooner the current must be reversed. There is, therefore, a width of brush which best satisfies both conditions.

Usually, however, where glowing occurs, the cause is too wide a brush, and often serious trouble from this cause can be entirely eliminated by varying the width of the brush perhaps only $\frac{1}{8}$ in.

72. Sparking Due to Rough Commutator.—First, the commutator surface may not be perfectly smooth after receiving its last turn off. The work may have been poorly done by the manufacturer, with the result that the commutator surface, instead of being left smooth, is somewhat rough. The result of this, especially with high-speed commutators, is that the brush does not make first-class contact with the commutator surface. It may chatter with attending noise, and thus with many motors (especially those of high voltage) the operation will be attended with sparking. As a result, the commutator surface, instead of becoming bright and smooth with time, becomes rough and dull or raw in appearance. Under these conditions the brushes do not make good contact, and, hence, the heat generated even under proper commutator conditions, owing to the resistance of brush contact, is multiplied several times, with consequent increase of temperature of the commutator. In addition, the friction of brush contact (which should give a coefficient of 0.2) is, with a rough commutator, much higher than it should be, which tends to increase the temperature.

73. Heating of commutator (Westinghouse Instruction Book) may develop from any of the following causes: (1) overload, (2) sparking at the brushes, (3) too high brush pressure, and (4) lack of lubrication on commutator.

74. Hot Commutator.—All this trouble (Sec. **72**) is cumulative. The result is that finally the temperature will rise to a point where the solder in the commutator will melt, perhaps short-circuiting or open-circuiting the winding. A commutator will stand very slight sparking, but where it is noticeable and where it is continued for long periods of time, trouble is apt to result. Where the load is usually very light on a motor, and where full load or overload are infrequent, a smoothing of the commutator occurs during the light-load period, which averts trouble. This is the reason that certain railway motors, which sometimes show sparking under their normal hour-rating load, give satisfaction as to commutation. The coasting of the car smooths up the imperceptible damage done by the sparking during the heavy load.

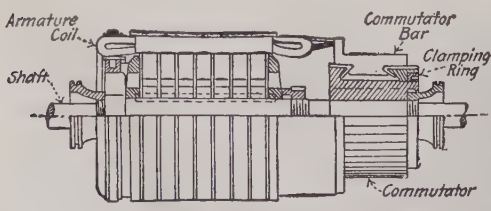


FIG. 44.—Section of d-c motor armature.

75. Loose Commutator Segments.—A further and more serious cause of sparking and commutator trouble is due to the fact that the commutator may not be "settled" when shipped by the

manufacturer. A commutator is made of many parts (Fig. 44), insulated one from another, and all bound together by mechanical clamping arrangements. The segments themselves are held by a clamp ring on each end, which must be insulated from them and should hold each segment individually from any movement relative to another.

Since the clamp must touch and hold down all segments, a failure to do so in any case results in a loose bar, which moves relatively to the next bar and causes roughness and thus sparking, with all its attendant accumulative troubles. The roughness of commutators due to poor turning or to poor design is shown uniformly over all the surface of the commutator on which brushes rest. A roughness due to a high or loose bar is shown by local trouble near the bad bar and its corresponding bars around the commutator. The jump of the brush occurs at the high bar and is the cause of the sparking (see also Secs. **77** and **78**).

76. Blackening of the Commutator.—Sparking due to a loose or high bar causes a local blackening instead of a uniform blackening, which occurs in case of poor design or poor commutator surface resulting from poor turning. Also, if the speed of the commutator is low enough, there will be a spark at the time the bad segment passes the brush. At ordinary speeds, or where there are several loose bars, the sparking in appearance will not be different from that due to poor design or poor turning. In such a case an examination of the commutator surface must be made to identify the cause.

It must be remembered that the slightest movement of a bar, especially with the higher voltage and high-commutator-speed machines, may cause the trouble. A splendidly designed motor may show very poor operation, owing to a commutator fault.

77. Grinding Commutators (Westinghouse Electric & Manufacturing Co.).—Resurfacing of a commutator should always be done with a grinding rig, whether it is to be ground concentric or in order to remove high bars or flat spots. A hand stone should never be used on a commutator to obtain a true surface, because it simply follows the irregularities in the surface and in some cases may even exaggerate them. The grinding rig consists of an abrasive stone set up similarly to a lathe tool in a rigging or carriage which may be moved back and forth in an axial direction and may be equipped with a radial feed. It should be supported very rigidly so that the stone is subjected to a very minimum of vibration. In large d-c equipment, such a rigging can be mounted on a brush arm by removing the brush holders on that arm. In some cases, it may even be desirable to brace the brush-holder bracket arm, while grinding, to obtain maximum rigidity. It is also possible by removing the brush rigging to support the grinder on parallels supported from the bedplate.

Grinding should be done when the machine is running in its own bearings and at rated speed in the case of a constant-speed machine. If

grinding is done at low speed, any slight unbalance will cause the commutator to run eccentric at rated speed.

Great care must be exercised to prevent copper and stone dust from entering the windings. The grinding rig should be equipped with a vacuum-cleaner arrangement, fitted over the stone to catch all dust. If a suction system is not available, the necks of the commutator and the front end windings should be protected by pasting heavy paper over them or by covering with a cloth hood properly applied.

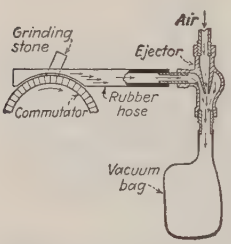


FIG. 45.—Method of commutator grinding showing dust collector. (*Westinghouse Electric & Manufacturing Co.*)

A simple, effective and inexpensive device for collecting dust during the grinding of commutators and collectors is illustrated in Fig. 45, and can be made from three small pieces of equipment, namely, (1) a 4-ft. length of 1½-in. rubber hose, (2) a vacuum bag from a household vacuum cleaner, and (3) a small ejector which may either be purchased or improvised from a 1½-in. Y pipe fitting.

At one end of the rubber hose cut away, in the form of a long arc, the bottom and about half of the sidewalls to fit the radius of the commutator or ring to be ground. Cut a hole in the hose in the middle of the remaining arc portion to fit the grinding stone. Fit the hose to the stone and commutator or ring so as to form an enclosure or "shoe" around the grinding surface to collect the dust. Attach the other end of the hose to the intake of the ejector. Attach the vacuum bag to the exhaust of the ejector. Use compressed air from a shop air line to produce the suction.

The stones used in grinding commutators might be classed as rough, medium, and fine. The rough stone has a grit of about 80 mesh and is used only where a very large amount of copper is to be removed. It should be used very seldom, because, if sufficient copper is to be removed to warrant its use, it would be better to take a cut off the surface in a lathe. The medium stone has a grit of about 120 mesh and is used for the bulk of the grinding work, the fine stone being used only to obtain a fine finish. The fine stone should have a grit of about 200 mesh.

After grinding, all commutator slots should be cleaned out thoroughly and the edges of the bars beveled. This beveling accomplishes two things; it removes the burrs caused by the stone dragging copper over the slots and eliminates the sharp edge at the entering side of the bar under a brush. The bevel on the bars is done with a special beveling tool and should be about $\frac{1}{32}$ in. chamfer at 45 deg., for medium thickness of bars. For thinner or wider bars, the beveling can be changed accordingly.

Practically all up-to-date machines have undercut mica. This undercutting should be kept $\frac{1}{16}$ in. deep $\pm \frac{1}{64}$ in. If it is apparent that enough copper is going to be removed by grinding so that the undercut-

ting will be shallow, the commutator should be reundercut before grinding. This is done by means of a small circular high-speed saw about 0.003 in. thicker than the nominal thickness of the mica. In undercutting, great care must be taken to see that a thin sliver of mica is not left against one side of the slot. Sometimes this sliver must be removed by scraping by hand.

After grinding, undercutting the mica, and beveling the edges of the bars, the commutator surface should be polished, while operating at rated speed. Aloxite or sandpaper should first be used (never emery cloth or paper) as this will remove the burrs due to beveling. After a very fine grade of sandpaper is used, a high polish can be obtained by burnishing the commutator with dense felt or canvas. A further improvement of the surface can even be secured if a small amount of light oil is applied to the canvas during the polishing.

78. Loose Commutator Clamp Rings.—First, draw the clamps of the commutator down firm, so that when the commutator is at normal temperature the clamping rings cannot be screwed down further without excessive effort. This is necessary so that all the bars may have a direct pressure from the clamp, rendering impossible any movement up or down. Second, after having drawn the clamps down, smooth off the surface of the commutator.

To get the clamps down firm, run the motor; if roughness appears, shut down at a convenient time, and, while hot, tighten the clamping rings. If it is found that the tightening bolts can be screwed up somewhat, the machine should again be put in service for at least 4 hr. At the end of this time shut it down again and make another trial on the tightening bolts. Now, if no more can be taken up on the tightening bolts, the commutator should be surfaced, either by turning with a tool or by grinding. If the clamps are down tight and the surface of the commutator has been properly smoothed, there will be no further trouble.

79. The Slotting of Commutators (Alan Bennett, *American Machinist*, Sept. 26, 1912).—There seems to be a prevalent idea that slotting should cure all commutator troubles, irrespective of their causes. This is not true, but slotting is a cure for certain specific troubles. Where the peripheral speed of the commutator is so slow that the dirt which may collect in the slots between commutator bars will not be thrown out by centrifugal force, slotting may aggravate rather than correct commutation difficulties (see Sec. **84**).

80. The principal reason for slotting commutators is to relieve the commutators of high mica, *i.e.*, mica that projects above the surface. High mica is generally due to one of two causes: either the mica is too hard and does not wear down at an equal rate with the copper, or the commutator does not hold the mica securely between the segments, allowing it to work out by the combined action of centrifugal force and the heating and cooling of the commutator.

It is evident that a commutator with a surface made irregular by projecting mica rotating at high speed under a brush must impart to the brush a vibratory action and thus impair the close contact that should exist between brush and commutator. The result is that sparking takes place more or less violently, depending on the condition of the commutator surface and the rate of speed.

This condition generally manifests itself after the machine has been running for some time, and in many cases will account for the development of sparking which did not occur at the time of installation. Often a case of this kind is aggravated by increasing the brush tension, causing a still faster rate of wear of copper over mica, with an attendant increased heating of the commutator.

81. What Is Accomplished by Slotting.—A harder brush may at times be used, with the idea of grinding off the mica and thus bringing it down to the commutator surface. Instead of curing the trouble, the commutator will, in the majority of cases, assume the raw appearance of being freshly sandpapered, instead of the glossy surface it should have, and both brush and commutator will wear rapidly.

This condition can be restored to normal and the commutator kept to a true surface by slotting, after which, with proper care and the use of proper brushes, commutator troubles will generally cease, provided the electrical design of the machine is not at fault. Even then there are cases that may be benefited to a certain extent by slotting, by reason of the good brush contact obtained. The majority of cases that show improvement are the ones in which the trouble is not inherent in the design of the machine but is due to mechanical causes.

With a slotted commutator it is possible to use a brush of fine grain and soft texture, inasmuch as there is not the same tendency to wear away the brush as with an unslotted commutator. The commutator will then take on the much-desired polish that is generally not possible with the harder brush. The life of both brush and commutator will be increased, and friction and the consequent heating will be reduced. These advantages will effect a saving that will more than offset the cost of slotting.

82. Various Methods of Slotting.—There is a variety of slotting devices on the market. Some are designed to operate with the armature swung between the centers of a lathe; others use a special tool in a shaper, with the armature secured to its bed. Still others are used by hand with the armature resting on blocks. In all cases the full width of the mica should be removed, and the resulting slot carefully cleaned from burrs and rough edges. It is not necessary that the slotting be carried deeply in the commutator. One-sixteenth inch is generally considered sufficient (see also Sec. **84**).

83. A slotted commutator should have proper and frequent care, as there is a chance of small particles of copper being dragged across from

bar to bar, and for dirt, oil, and carbon dust to accumulate in the slots and short-circuit the commutator.

84. High Mica in Commutators.—Some motors, under certain conditions, roughen up their commutators after a short term of service, although there seems to be no excessive sparking under or at the edges of the brushes. This may occur even though the commutator has been well "settled." The commutator acts as if the mica used between bars to insulate the various segments, one from another, had protruded upward, causing roughness and excessive sparking.

Actual raising of the mica is a very rare occurrence, and, if it occurs, does so at certain spots and is easily and positively identified. An actual uniform protruding of mica, all over a commutator, as described, is practically an unknown phenomenon. What actually does occur is an eating away of the copper surface of the commutator, leaving the high mica between the bars. A good machine will not spark enough to cause this condition. A poor machine will.

The phenomenon is easily identified, as the commutator surface looks raw all over instead of smooth and bright with a good brown gloss. If allowed to continue, a general roughness appears, accompanied by sparking, until finally the sparking and heating will increase so much that the machine may flash over from brush to brush, blowing the fuses or opening the circuit breakers. The trouble is aggravated if the motor operates continuously under heavy load. If there are periods of light load, the commutator has an opportunity to be smoothed down by the brushes. This condition is appreciated by railway motor designers. A railway motor coasts a considerable portion of the time. Thus the commutator is smoothed, neutralizing the roughening occurring under load.

85. To Remedy a Roughened, High-mica Commutator.—(1) Use it on work where the load is somewhat intermittent; (2) replace it altogether; or (3) slot the commutator. Then, as there are no longer two different materials to wear down or to be worn away by sparking, an unequal surface will not result. The mica need be cut down only $\frac{1}{16}$-in., and a narrow, sharp chisel will do the work satisfactorily. No trouble will result from short-circuiting in this case, since centrifugal force keeps the slots clean. Some manufacturers ship machines with slotted commutators.

86. Brush Troubles.—When there is an excessive drop in speed from no load to full load, the position of the brushes on the commutator should (Sec. **45**) first be investigated. No brush position that causes sparking should be chosen. The following sections outline brush troubles and their remedies.

87. Sparking of the brushes may be due to one of the following causes (Westinghouse Instruction Book); see also Dynamo-defects Table: (1) The machine may be overloaded. (2) The brushes may not be set exactly

at the point of commutation—a position can always be found where there is no perceptible sparking, and at this point the brushes should be set and secured. (3) The brushes may be wedged in the holders. (4) The brushes may not be fitted to the circumference of the commutator. (5) The brushes may not bear on the commutator with sufficient pressure. (6) The brushes may be burned on the ends. (7) The commutator may be rough; if so, it should be smoothed off. (8) A commutator bar may be loose or may project above the others. (9) The commutator may be dirty, oily, or worn out. (10) The carbon in the brushes may be unsuitable. (11) The brushes may not be equally spaced around the periphery of the commutator. (12) Some brushes may have extra pressure and may be taking more than their share of the current. (13) Mica may be high. (14) The brushes may be vibrating. (15) Brush toes may not be in line.

These are the more common causes, but sparking may be due to an open circuit or loose connection in the armature. This trouble is indicated by a bright spark which appears to pass completely around the commutator and may be recognized by the scarring of the commutator at the point of open circuit. If a lead from the armature winding to the commutator becomes loose or broken it will draw a bright spark as the break passes the brush position. This trouble can be readily located, as the insulation on each side of the disconnected bar will be more or less pitted. The commutator should run smoothly and true, with a dark, glossy surface.

88. Glowing and Pitting of Carbon Brushes.—This may be due to either of two causes: poor design or a wrong position of the brushes on the commutator. The error of design may be only in the choice of width of carbon brush used. The pitting is due to glowing. If the glowing is at the edge of the carbon it is plainly visible and easily located. It may, however, occur underneath the carbon so that only with difficulty can it be seen. Such glowing pits the carbon face by heat disintegration. With some machines three-fourths of the brush face may be eaten away and the pits may be, perhaps, $\frac{1}{4}$ to $\frac{1}{2}$ in. deep when discovered. A usual (incorrect) decision is that the current per square inch of contact is too great, the calculation being made by dividing the *line amperes* by *the square-inch cross section of either the positive or the negative brushes.* If this calculation gives a value under 45 or 50, it is certain that the cause of the trouble has not been judged correctly.

The real cause of the glowing is, to be sure, excessive current through the carbon, but this is not the line current if the calculation, as stated, shows a brush-face density below 50 amp. per sq. in. It is a local current caused by the short-circuiting of two or more segments of the commutator by the brush resting upon them. The usual overlap of a carbon brush is about two segments, and, while these two segments are under the brush, the armature coils connected to them are short-circuited. If the design of the machine is such that the coil so short-circuited encloses stray flux

from the pole tip, this flux will create in the short-circuited coil a current, perhaps many times larger than the brush is capable of carrying, with the result that the glowing and pitting occurs.

89. Chattering of brushes is sometimes experienced on d-c machines. Chattering under certain conditions may become so prominent as not only to be of annoyance, but also actually to break the carbons. An examination of the commutator will reveal no roughness, the surface being, perhaps, perfectly smooth and bright. This trouble occurs principally with the type of brush holder which has a box guide for the carbon. The spring which forces the brush into contact rests on top of the carbon, which has fairly free play in the box guide. Chattering

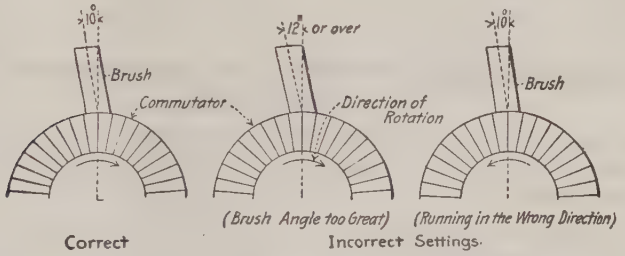


FIG. 46.—Methods of setting brushes.

usually occurs with high-speed commutators, running at 4,000 to 5,000 ft. per min. peripheral speed.

Such brush holders are necessary on commutators which, like those on engine-driven machines, may run out of true on account of the shaft play in the bearings caused by the reciprocating motion of the engine. The clamped type of holder is usually free from bad chattering but rocks on a commutator that runs out, causing poor contact and perhaps sparking.

Lubricating the commutator causes the chattering to disappear immediately, but there is no commutator compound which gives a lubricating effect lasting over possibly ½ hr. Thus it is not practical to lubricate often enough to prevent the chattering. There will be no chattering if the angle of the brush with the radial line, passing through the center of the carbon and the center of the commutator, is less than 10 deg. and if the carbon trails on the commutator instead of leads. Figure 46, I, shows the setting which will stop all serious chattering, and Fig. 46, II and III, shows settings which may give trouble.

90. Low Speed.—The fault may be in the winding of the armature or field, in which case a remedy is difficult. Considerable range of speed can be obtained by the choice of brush position on the commutator. For many motors a speed variation of 15 per cent may be obtained, without sparking, by brush shift. Therefore, if the discrepancy of speed is within

this amount, the brushes should be moved to counteract it. A backward shift of brush gives increased speed, and a forward shift decreased speed. At any brush position, however, there must be practically no sparking. A first-class motor should run at full load within 4 per cent (up or down) of the name-plate speed if the voltage is as specified on the name plate. The speed at no load should not be more than 5 per cent higher than this; also the speed at full load, hot, should not be over 5 per cent greater than the speed at full load, cold.

91. Bearing Troubles of D-c Motors and Generators.—See Troubles of A-c Motors and Generators.

92. Sporadic motor sparking has been known to occur on account of irregular short circuits on the line which were caused by the wind blowing the line wires together.

PRINCIPLES, CHARACTERISTICS, AND MANAGEMENT OF A-C GENERATORS

93. Types of A-c Generators.—The different types of a-c generators (alternators), classified according to the method of producing the voltage are listed below:

1. Synchronous alternators.
   a. Revolving field.
   b. Revolving armature.
2. Induction alternators.
   a. Stator winding is source of voltage.
   b. Rotor winding is source of voltage.
3. Inductor alternators.

94. Synchronous a-c generators are discussed in an elementary way in Secs. **47, 105, 138, 141,** and **145** of Div. 1. These generators may be constructed either with the armature or the field structure as the revolving member. Small generators up to 50 kw. are commonly made with the revolving-armature construction. Practically all other synchronous alternators employ the revolving-field construction. The required magnetic field is produced by d-c electromagnets, which are excited by a small d-c generator or exciter. The fundamental construction and connections for a revolving-field alternator are shown in Fig. 47.

95. The e.m.f. in a synchronous alternator is generated as suggested in Fig. 48. As each field coil, *D* for instance, sweeps past the armature coils the lines of flux from the field coil cut the armature coils. As coil *D* passes from *A* to *C* an alternating e.m.f. represented by the curve *ABC* will be generated in the armature. It should be understood that in commercial alternators the armature coils are set in slots and differently arranged than in Fig. 48, which only illustrates a principle.

The value of the voltage generated by a given synchronous alternator

depends upon the speed and d-c field current. Since the speed must be held constant in order to maintain the proper frequency, the voltage must be controlled by adjustment of the field current.

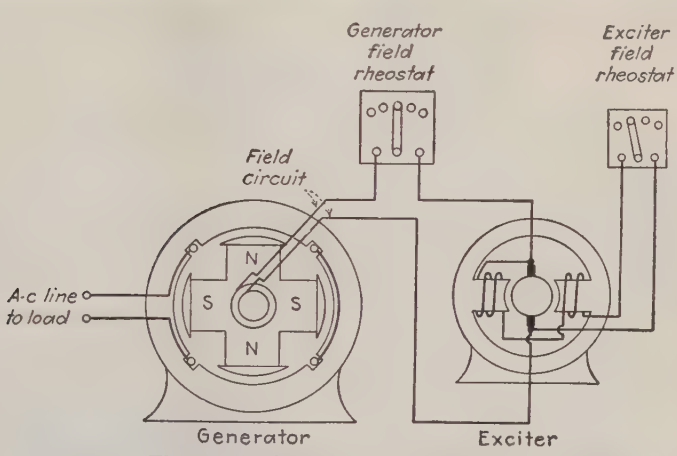


FIG. 47.—Elementary diagram of a-c generator and exciter.

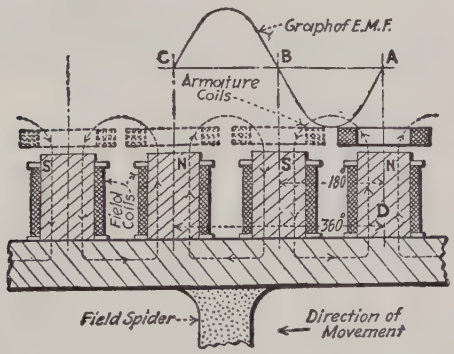


FIG. 48.—Armature and field structure developed.

96. The speed and number of poles of an alternator determine the frequency which it generates.

$$f = \frac{p \times \text{r.p.m.}}{120}; \quad \text{or} \quad p = \frac{120f}{\text{r.p.m.}}; \quad \text{or} \quad \text{r.p.m.} = \frac{120f}{p} \quad (1)$$

where f = frequency in cycles per second. r.p.m. = revolutions per minute of rotor; and p = the number of field poles.

Example.—What is the frequency of a two-pole alternator running at 3,600 r.p.m.?

Solution.—Substitute in the formula

$$f = \frac{p \times \text{r.p.m.}}{120} = \frac{2 \times 3{,}600}{120} = \frac{7{,}200}{120} = 60 \text{ cycles per sec.}$$

Example.—How many poles has a 25-cycle alternator running at 500 r.p.m.?
Solution.—Substitute in the formula

$$p = \frac{120f}{\text{r.p.m.}} = \frac{120 \times 25}{500} = \frac{3.000}{500} = 6 \text{ poles}$$

97. Synchronous Speeds—A-c Generators and Motors

Application to Generators.—The table shows the speeds at which the rotor of an alternator which has a given number of field poles must turn to generate voltage at given frequencies.

Application to Motors.—The table indicates the synchronous speed of the rotary magnetic field of an induction motor having a given number of poles and taking current at a given frequency.

The table also shows the speeds of synchronous motors having a given number of field poles and taking currents at given frequencies.

Number of poles	R.P.M. when frequency is											
	25	30	33⅓	40	50	60	66⅔	80	100	120	125	133⅓
2	1,500	1,800	2,000	2,400	3,000	3,600	4,000	4,800	6,000	7,200	7,500	8,000
4	750	900	1,000	1,200	1,500	1,800	2,000	2,400	3,000	3,600	3,750	4,000
6	500	600	667	800	1,000	1,200	1,333	1,600	2,000	2,400	2,500	2,667
8	375	450	500	600	750	900	1,000	1,200	1,500	1,800	1,875	2,000
10	300	360	400	480	600	720	800	960	1,200	1,440	1,500	1,600
12	250	300	333	400	500	600	667	800	1,000	1,200	1,250	1,333
14	214	257	286	343	428	514	571	686	857	1,029	1,071	1,143
16	188	225	250	300	375	450	500	600	750	900	938	1,000
18	167	200	222	267	333	400	444	533	667	800	833	889
20	150	180	200	240	300	360	400	480	600	720	750	800
22	136	164	182	217	273	327	364	436	545	655	682	720
24	125	150	167	200	250	300	333	400	500	600	625	667
26	115	138	154	185	231	280	308	370	461	554	577	615
28	107	128	143	171	214	257	286	343	429	514	536	571
30	100	120	133	160	200	240	267	320	400	480	500	533
32	94	113	125	150	188	225	250	300	375	450	487	500
36	83	100	111	133	166	200	222	266	333	400	417	444
44	79	82	91	109	136	164	182	218	273	327	341	363
48	63	75	83	100	125	150	167	200	250	300	312	333
54	56	66	74	90	111	133	148	178	222	266	278	296
60	50	60	67	80	100	120	133	160	200	240	250	266
68	44	53	59	71	88	106	118	141	176	212	221	235
72	42	50	55	67	83	100	111	133	166	200	208	222
96	31	38	42	50	64	75	82	100	125	150	156	167
100	30	36	40	48	60	72	80	96	120	120	150	160

98. Single-phase Alternators.—The circumferential distance from the center line of one pole to the center line of the next pole of the same

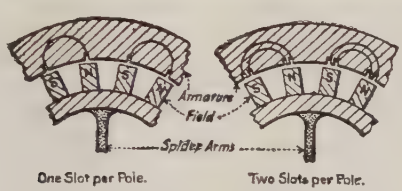


FIG. 49.—Single-phase armature windings.

polarity constitutes 360 electrical degrees. See Fig. 48 which shows how a single-phase e.m.f. is generated. Figure 47 is a diagrammatic illustra-

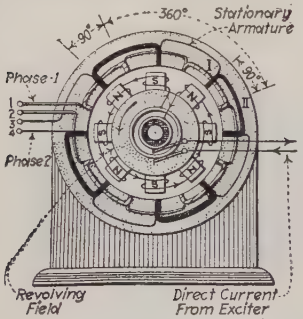


FIG. 50.—Diagram for two-phase alternator.

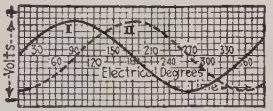


FIG. 51.—Graphs of two-phase current.

tion of a single-phase alternator, and Fig. 49 shows, diagrammatically, two different kinds of single-phase windings. Single-phase alternators are seldom made now. The manufacturers furnish three-phase machines

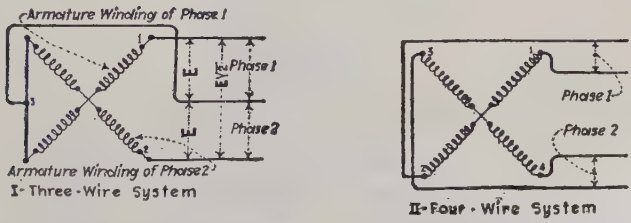


FIG. 52.—Methods of connecting two-phase generator armature windings.

instead and give them a single-phase rating equal to about 70 per cent of the three-phase rating. The single-phase load is carried on two of the three leads of the three-phase generator (see Three-phase Alternator).

99. Two-phase Alternator.—In a generator of the type indicated in Fig. 50, the centers of the two component coils I and II are situated 90

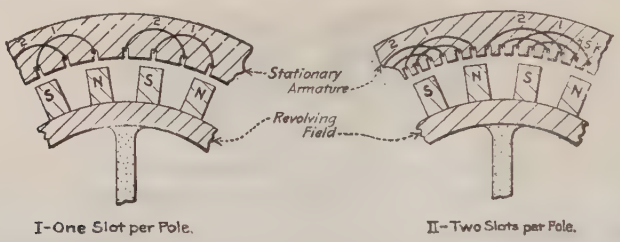


Fig. 53.—Two-phase armature windings.

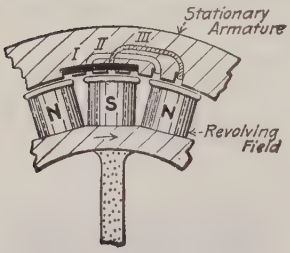


Fig. 54.—Six-phase grouping.

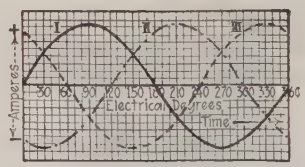


Fig. 55.—Graphs of three-phase currents.

electrical degrees apart, and the single-phase e.m.fs. generated in coils I and II by the passage of the field system past them differ in phase by

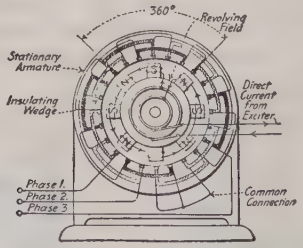


Fig. 56.—Diagram for three-phase, Y-connected alternator.

90 degrees. This property has given rise to the term quarter-phase for this type of machine, but it is more frequently called a two-phase machine. The e.m.f. in coil I is zero when that in coil II is a maximum, and vice

versa. The curves of e.m.f. in coils I and II may be plotted as indicated in Fig. 51. Figure 52 shows two methods of connecting the armature windings of two-phase alternators. The armature coils can be arranged in one or more slots per pole per phase, as diagrammatically suggested in Fig. 53. In commercial machines the windings are almost always arranged in more than one slot per pole. (See Div. 1 for further information in regard to two-phase currents.)

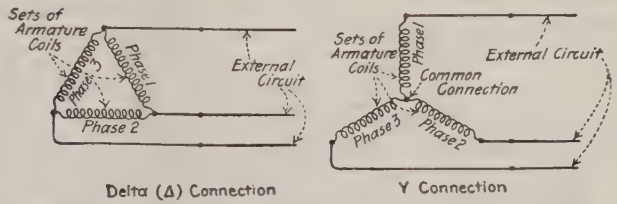


FIG. 57.—Methods of connecting three-phase armature coils.

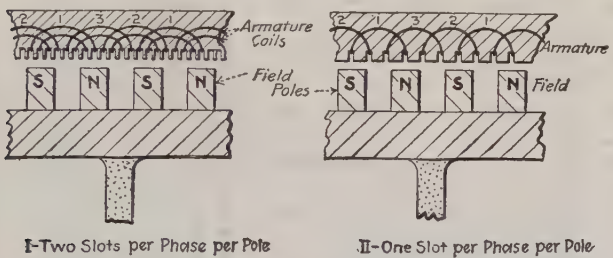


FIG. 58.—Three-phase armature windings.

100. Three-phase alternator coils are arranged as illustrated diagrammatically by coils, I, II, and III of Fig. 54, and the curves of instantaneous e.m.f. are displaced from one another by 120 electrical degrees as indicated in Fig. 55. These curves also represent the e.m.fs. for the winding in Fig. 54. Here three coils are distributed (60 electrical degrees apart) over a pole pitch, and the phase displacement between the e.m.fs. is 60 degrees. However, if in connecting the coils the middle coil is connected in the reverse sense from the other two, the result will be three voltages 120 electrical degrees apart, as shown in Fig. 55.

The two methods of connecting three-phase armature windings are shown in Fig. 57. These methods are discussed in more detail in Div. 1. Armature windings can be arranged in one or more slots per pole per phase (Fig. 58). The Y method of connection is almost always used for three-phase generators.

101. Approximate Performance Values of A-c Generators

220, 440, 600, 1,100, 2,200 and 2,400 Volts. Two-phase and three-phase.

It should be understood that values will vary somewhat with speed and other conditions. Those given are general and approximate only and do not apply to any particular manufacturers' line.

A slow-speed machine is assumed to be one turning at from 100 to 200 r.p.m.; a medium-speed machine, one turning at from 200 to 300 r.p.m.; and a high-speed machine, one turning at from 300 to 1,200 r.p.m. In the table, S indicates slow speed, M medium speed, and H high speed.

Output, kva.		Current, Three-phase				Efficiency			Exciter capacity required
		240 volts	480 volts	600 volts	2,400 volts	½ load	¾ load	Full load	
50	S	120.3	60.1	48.0	12.0	85.5[a]	88.0[a]	89.0[a]	7.0
	M					86.6	89.8	90.8	2.0
	H								
75	S	180.4	90.2	72.2	18.0	88.0[a]	90.0[a]	91.3[a]	8.0
	M					87.1	89.7	90.8	3.0
	H								
100	S	240.6	120.3	96.2	24.1	89.0[a]	91.0[a]	92.0[a]	9.0
	M					87.7	90.2	91.3	3.0
	H								
125	S	301.0	150.0	120.0	30.1	91.0[a]	92.0[a]	92.5[a]	9.0
	M					90.1	91.7	92.7	5.0
	H								
150	S	360.8	180.4	144.3	36.1	90.5[a]	91.7[a]	92.2[a]	14.0
	M					91.0	92.0[a]	93.0[a]	9.0
	H					90.2	91.8	92.8	4.5
200	S	481.1	241.6	192.4	48.1	90.7[a]	92.3[a]	93.4[a]	12.0
	M					91.0	93.0[a]	93.5[a]	11.0
	H					90.1	92.7	93.5	6.0
300	S	723.0	362.0	289.0	72.0	91.0[a]	93.0[a]	93.5[a]	20.0
	M					92.0[a]	93.5[a]	94.2[a]	15.0
	H					89.2	92.1	93.2	12.0
400	S	962.0	481.0	385.0	96.2	92.0[a]	93.0[a]	94.0[a]	23.0
	M					92.0[a]	94.0[a]	94.5[a]	14.0
	H					90.2	92.3	93.8	12.0
500	S	1,203.0	602.0	481.0	120.0	92.5[a]	94.0[a]	94.5[a]	23.0
	M					91.8	93.5	94.4	16.0
	H					90.8	93.5	94.5	13.0
600	S	1,450.0	722.0	578.0	144.0	92.5[a]	94.0[a]	94.5[a]	28.0
	M					92.4	94.1	94.8	22.0
	H					90.0	92.4	93.8	20.0
700	S	1,690.0	841.0	673.0	168.0	93.0[a]	94.0[a]	94.6[a]	35.0
	M					91.8	94.1	95.0	24.0
	H					90.0	92.5	94.0	20.0
800	S	1,930.0	977.0	773.0	193.0	92.8[a]	94.5[a]	95.3[a]	32.0
	M					92.1	94.0	95.0	23.0
	H					91.5	93.0	94.0	17.0
1,000	S	2,406.0	1,203.0	962.0	241.0	93.0[a]	94.0[a]	94.8[a]	35.0
	M					92.3	94.2	95.0	29.0
	H					92.5	94.0	94.6	25.0
1,250	S	3,000.0	1,500.0	1,200.0	300.0	93.5[a]	94.5[a]	95.7[a]	38.0
	M					92.5	94.6	95.5	30.0
	H					92.0	94.2	95.3	26.0
1,500	S	3,640.0	1,804.0	1,443.0	361.0	93.6[a]	94.7[a]	95.4[a]	42.0
	M					92.2	94.4	95.5	38.0
	H					93.0	95.1	95.9	22.0
2,000	S	4,850.0	2,420.0	1,924.0	481.0	94.0[a]	95.0[a]	95.8[a]	50.0
	M					92.6	94.8	95.8	42.0
	H					92.3	94.7	95.7	38.0

[a] Engine-type machines: efficiencies do not include friction of bearings.

102. Exciters for a-c generators are compound-wound d-c generators, flat-compounded and rated at 125 volts for the smaller sizes of generators and at 250 volts for the larger sizes. The systems of excitation which are in general use are:

1. Individual exciter for each generator unit.
   a. Direct connected to the alternator shaft.
   b. Belt connected to the alternator shaft.
2. Exciter-bus system supplied by one of the following combinations:
   a. Induction-motor-driven exciters and steam-driven exciters.
   b. Induction-motor-driven exciters and hydraulic-turbine-driven exciters.

The individual exciter unit (Fig. 59) has the advantage of rapid response at time of system short circuits or rapid fluctuations in load. It also has a high efficiency due to being driven by the highly efficient

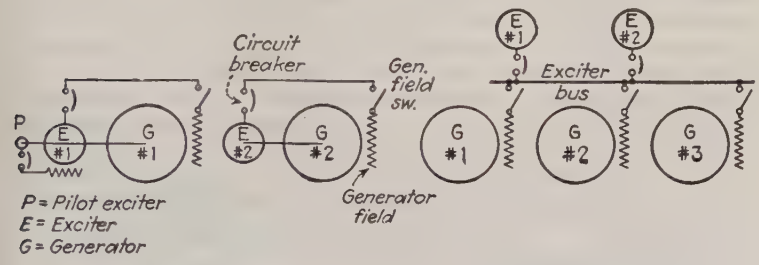


FIG. 59.—Systems of excitation for a-c generators.

prime mover of the generator and due to eliminating the loss in a generator field rheostat, since the generator voltage is controlled through variation of the field current of the exciter. The direct connection to the generator shaft is used for 1,200-, 1,800- and 3,600-r.p.m. alternators. The belt connection is ordinarily used for slower speed alternators so that a cheaper, higher speed exciter (usually 1,800 r.p.m.) can be used.

The exciter-bus system (Fig. 59) has the advantages of not crippling the alternator because of trouble with the exciter and of keeping closer voltage regulation in cases where the prime mover driving the alternator is subject to speed variations. With this system at least two of the exciters should be steam or hydraulic driven so as to ensure being able to start the plant up after a shutdown.

Since failure of the excitation power will of necessity produce a failure of the a-c generation and possible shutdown of the station, it follows that the exciter system should be made as reliable as possible. With the exciter-bus system there should be at least one or two spare exciter units.

In some plants, for extreme reliability a storage battery is floated on the exciter bus to ensure continuity of the d-c excitation. Induction motors should be used for driving the exciters, because they can be started rapidly and will not fall out of step during voltage fluctuations caused by short circuits on the system.

Frequently with the individual-exciter system, pilot exciters are used to supply the field of the main exciter. This adds to the rapidity of response to voltage fluctuations.

103. Synchronizing.—Two or more a-c generators will not operate satisfactorily in parallel unless (1) their voltages, as registered by a voltmeter, are the same; (2) their frequencies are the same; and (3) their voltages in phase. If the machines are not in phase, even if their indicated voltages and their frequencies are the same the voltage of one will, at given instants, be different from that of the other, and there will be an interchange of current between the machines. When two or more generators all satisfy the three above requirements, they are in synchronism. Synchronizing is the operation of getting machines into synchronism. Incandescent lamps or instruments are, as described in other paragraphs, used for indicating when machines are in synchronism.

104. Synchronizing a Single-phase Circuit with Lamps.—The elementary principle involved in determining synchronism is indicated in Fig. 60.

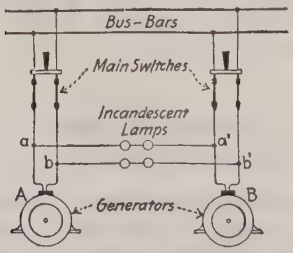


FIG. 60.—Circuits for synchronizing with lamps.

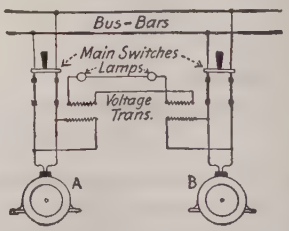


FIG. 61.—Circuits for synchronizing high-voltage circuits with lamps.

If the voltage and frequency of generators A and B are the same and the machines are in phase, point a will be at the same potential at every instant as will point a'. Hence the lamps between a and a' will not light so long as the three conditions are satisfied. So long as the conditions are not satisfied there will be a fluctuating cross-current from a to a' and a constant fluctuating of the brilliancy of the incandescent lamps. When the lamps become dark and remain so, the generators are in synchronism and may be thrown together. Had the connection at a' been made to the b' generator lead, the lamps would be bright when the generators were in synchronism, but for reasons outlined in another paragraph the connection shown, which provides the dark-lamp method

of synchronizing, is preferred. The same conditions occur in the b—b' set of lamps as in the a—a' set. A voltmeter of proper rating can be substituted for the lamps.

Where the voltage generated is so high that it is not desirable to connect a sufficient number of lamps in series for it, a single lamp fed through voltage transformers can be used for synchronizing, as suggested in Fig. 61.

105. Phasing-out Three-phase Circuits.—Prior to connecting the leads, from a polyphase generator that is to operate in parallel with others, to the generator switch, the circuits must be "phased-out," *i.e.*, the leads must be so arranged that each lead from the generator will, when the generator switch is thrown, connect to the corresponding lead of the other generator. If this is not arranged there may be considerable damage done, owing to an interchange of current when the two machines are parallel. After once phasing-out it is necessary to synchronize but one phase of the machine with the corresponding phase of the other machine.

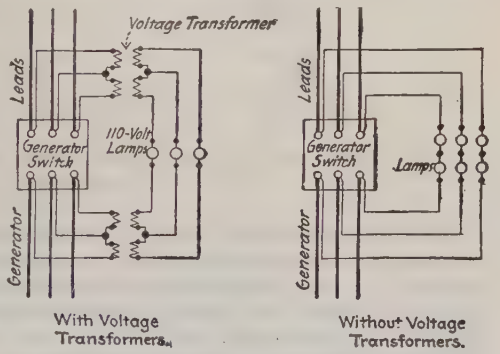


FIG. 62.—Connections for phasing out three-phase circuits.

Connections for phasing-out three-phase circuits are shown in Fig. 62. If voltage transformers are not used, the sum of the voltages of the lamps in each line should be approximately the same as the voltage of the circuits. On 440-volt circuits, two 220-volt or four 110-volt lamps should be used in each phasing-out lead.

To phase-out, run the two machines at about synchronous speed. If the lamps do not all become bright and dark together, interchange any two of the main leads on one side of the switch, leaving the lamps connected to the same switch terminals, after which the lamps should all fluctuate together, which indicates that the connections are correct. The machines are in phase when all the lamps are dark.

106. The synchronizing connections for three-phase generators are shown in Fig. 63. A synchronizing plug may be used instead of the single-pole synchronizing switch shown. The illustration indicates the connections used where machines are to be synchronized to a bus. Where only two machines are to be synchronized, the connections are the same as shown in Fig. 63, except that the bus transformer and the corresponding lamp are omitted and one plug is required instead of two.

107. Synchronizing Dark or Light.—Synchronizing dark appears to be the preferable method. All the connections shown are for "synchronizing dark." When the lamps are "dark" the machines are in phase, and it is necessary to close the switch when the pulsation is the slowest obtainable or ceases altogether, *i.e.*, at or just before the middle of the longest dark period.

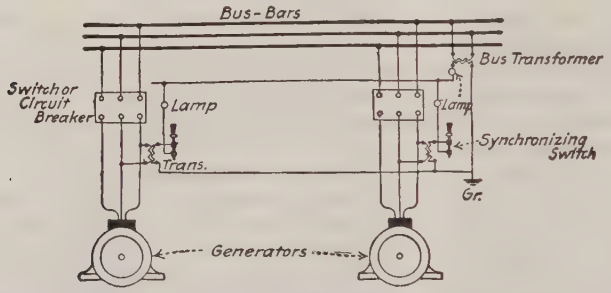


FIG. 63.—Connections for synchronizing three-phase circuits where transformers are required.

Should a filament break, the synchronizing lamps would remain dark and thus apparently indicate synchronism and possibly cause an accident. Therefore it is considered desirable by some to reverse the synchronizing circuit connections and thereby synchronize "light." Synchronizing light eliminates the danger due to the breaking of a filament but has the disadvantage that the time of greatest brilliancy is difficult of determination. The "light" period is relatively long compared with the dark period so that synchronizing light is usually considered the more difficult and were it not that with the "synchronizing-light" method the danger due to filament breakage is eliminated, the method would never be used.

The probability of a filament breaking just at the time of approaching synchronism, and when the machines are not in phase, is remote. If it occurs at any other time in the operation it will be noticed. As a protection against accidents due to breakage, two synchronizing lamps should always be placed in multiple.

108. The number of lamps to use in a group to indicate synchronism is determined by the voltage of the generators. With high-voltage circuits it is not feasible to use a sufficient number of lamps, so a transformer is employed that has a secondary voltage of 110 volts. See the diagrams. The greatest voltage impressed on the lamps is double that of one generator or the secondary voltage of one transformer. Thus the maximum voltage on the lamps where two 220-volt generators are being synchronized is 440 volts. The dark period may be shortened by impressing a voltage higher than their normal on the lamps. For two

220-volt machines, for example, three 110-volt lamps might be used, but the life of the lamps would be greatly reduced.

109. A synchroscope (see Fig. 64) is an instrument that indicates the difference in phase and frequency between two alternators. It shows whether the machine to be synchronized is running fast or slow. The pointer rotates clockwise if the machine is running fast and counterclock-

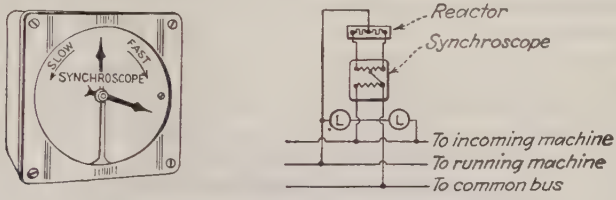


FIG. 64.—Synchroscope and wiring diagram.

wise if it is running slow. When the pointer remains stationary pointing upward, the machines are in synchronism. It is quite common to use two synchronizing lamps in addition to a synchroscope so that one system is a check against the failure of the other. Should the lamps remain dark for any greater length of time than a few seconds, the operator should look for trouble either in the lamps or the connections. After the main switches have been thrown, thus connecting the machines in parallel, the machines will hold themselves in synchronism.

110. Although for successful parallel operation it is not necessary that a-c generators be of the same type, output, and speed, it is universally conceded that the question of wave shape is important, since, if the waves are of different shapes, cross-currents will always be present. Similar wave shapes are more readily obtained with machines of similar type. Satisfactory parallel operation, the previously mentioned conditions being fulfilled, consists in obtaining:

1. Correct division of the load among the machines.
2. Freedom from hunting.

111. Division of Load.—Machines with similar characteristics tend to divide the common load proportionally to the ratings of the machines. Such a proportional load division may be disturbed if the steam supply to the engines is defective or variable from any cause. The steam supply is regulated by the engine governors, and defects in one or more of these governors will give rise to poor load division. It is essential that the governors of all the engines shall have similar speed-regulation characteristics so that a sudden change in the load shall cause the same amount of regulation on each engine. Correct load division is therefore essentially a problem for the engine governors.

Varying the voltage of an alternator running in parallel with others by adjusting its field rheostat will not vary the load on it as with a d-c

generator. To increase the energy delivered by an alternator it is necessary that the prime mover be caused to do more work. An engine should be given more steam or a water wheel more water.

112. Adjustment of Field Current.—When the rheostats of two alternators running in parallel at normal speed are not adjusted to give a proper excitation, a cross current will flow between the armatures. The intensity of this current depends only upon the difference in the field currents and the impedances of the armature windings. It may vary over a wide range, from a minimum of zero when both field currents are normal, to more than full-load current when they differ greatly. The effect of this cross current is to increase the temperature of the armatures and, consequently, to decrease the allowable useful output of the generators. It is important that the rheostats be so adjusted as to reduce it to a minimum. This cross current registers on the ammeters of both generators and usually increases both readings. The sum of the ammeter readings will be minimum when the idle or cross current is zero.

In general, the proper field current for a machine running in parallel with others is that which it would have if running alone and delivering its load at the same voltage. In order to determine the proper position of the rheostats it is necessary to make trial adjustments after the alternators are paralleled, until that position is found at which the sum of the ammeter readings is minimum.

To illustrate this method let us consider two similar alternators, *A* and *B* (Fig. 65), operating in parallel. When the generator field rheostats of both are properly adjusted, no cross currents will flow through the armatures, and the main ammeters will show equal readings if each machine is receiving the same amount of power from its prime mover. If the rheostat of *A* is partly cut in so as to reduce its field current, a cross current lagging in *B* and leading in *A* will flow between the armatures, the effect of which will be to strengthen *A*'s magnetization and weaken *B*'s until they are approximately equal. The resultant e.m.f. of the system will thereby be lowered.

On the other hand, if the rheostat of *B* is partly cut out so as to increase its field current, a cross current leading in *A* and lagging in *B* will flow between the armatures, strengthening *A's* magnetization and weakening *B's* magnetization until they are again equal. The resultant e.m.f. of the system will thereby be raised. A cross current of the same character is therefore produced by decreasing one field current or increasing the other *i.e.*, in both cases it will lead in the first machine and lag in the second. The e.m.f. of the system will, however, be decreased in one case and increased in the other.

It is obvious that by simultaneously adjusting the two rheostats the strength of the cross current may be varied considerably and the e.m.f. of the system maintained constant.

For the first trial adjustment, cut in *A's* rheostat several notches and

cut out *B's* the same amount, so as not to vary the e.m.f. of the system. If this reduces the sum of the main ammeter readings, continue the adjustment in the same direction until the result is minimum. After this point is reached a further adjustment of the rheostat in either direction will increase the ammeter readings. If the first adjustment increases the sum of the ammeter readings it is being made in the wrong direction, in which case move the rheostats back to the original positions and then cut out *A's* rheostat and cut in *B's*. If both adjustments increase the

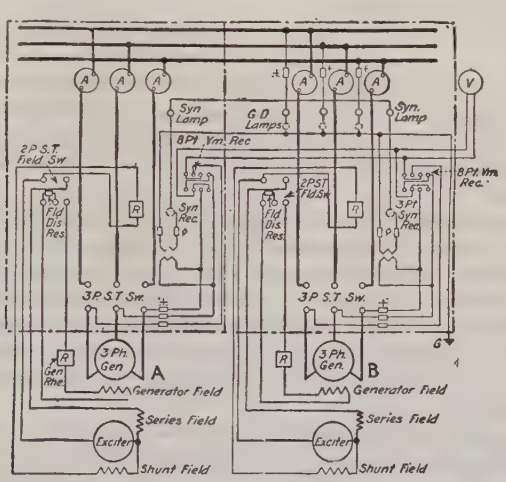


FIG. 65.—Two three-phase alternators of similar characteristics operating in parallel.

sum of the ammeter readings the original positions of the rheostats are the proper ones.

In making these adjustments of the rheostats it may be found difficult to locate the exact points at which the cross current is minimum, as it may be possible to move the rheostats over a considerable range when near the correct positions without materially changing the ammeter readings. When the adjustment is carried this far, it is close enough for practical operation. If the generators are provided with power-factor meters, the same result may be obtained by adjusting the field currents until all the power-factor meters read the same, at the same time maintaining the voltage constant.

113. Hunting ("Standard Handbook for Electrical Engineers") is a term employed to describe the oscillations of the revolving masses of the machines when they are accelerated and retarded above and below the normal average speed. If this hunting or swinging be allowed to exceed a certain amount, the operation of the machines becomes unstable,

and they may break out of step. Freedom from cumulative hunting is consequently essential. The swinging action is set up primarily by variations in the rotative speed resulting from irregularity in the turning force. A perfectly uniform turning moment or turning force cannot be obtained with reciprocating engines. The irregularity in the turning moment during a revolution results from the following causes:

1. Defective distribution of steam in cylinders.
2. Short connecting rod.
3. Inertia of moving parts.

If one of two machines running in parallel momentarily lags behind the other, its armature receives a current which tends to pull the machine into phase and accelerate it. At the instant it reaches the correct phase position its speed may be a little greater than that of the other machine, which is now in turn accelerated. The machines are now alternately lagging and leading with relation to one another. In other words, hunting is set up.

Whichever engine is, for the instant, accelerating will have its steam supply cut down by the governor. If the governor is too sensitive, it will overgovern, cutting down the steam and the speed too far. An instant later the overgoverning will be in the opposite sense, and this process will repeat itself. Similar occurrences will simultaneously be taking place on the other engine, and thus we have a case of hunting governors. By this hunting, the steam supply is rendered periodic and varies between two limits.

114. Surging is the term used in connection with the current variations during the hunting, the latter term applying to the mechanical phenomenon of periodic speed variations. The case described is an instance of hunting in the governors due to change of load and to oversensitiveness of the governors. If, however, the governors are sluggish, a time interval elapses between an accidental acceleration and its correction by the governor. This lag in response will tend to set up hunting.

115. Prevention of Hunting.—The variations in turning moment and angular speed may be greatly reduced by the use of a heavy flywheel, as this tends to keep the rate of revolution uniform by virtue of storing energy and giving it out again during the course of each revolution. The flywheel, however, must not have too great a moment (*i.e.*, it must not be too big) as it adds to the inertia of the moving parts and may prolong hunting if once started. Hunting may sometimes be overcome by damping the governor so that it will not respond to small and quick variations in speed, such as occur during one revolution, but will respond only to steady and continued changes in speed. This result is obtained by fitting each governor with a suitable dashpot so that it is rendered more sluggish and will make no alteration in the steam supply except when the force acting on the governor is continued for some length of time.

The tendency to hunt may sometimes be prevented by synchronizing the engines so that the cranks on all the engines are in step, and the variations in turning moment are coincident in all the engines. This plan is sometimes effective, so far as the prevention of hunting in the generating station is concerned, but it cannot always be utilized owing to the time taken to get the cranks in step, especially as an engine must be run up in a few minutes when the load is coming on quickly. It also is apt to intensify the hunting of the apparatus in distant substations.

With steam-turbine-driven generators, this hunting difficulty is much more rare—practically unknown—and the use of high and uniform speeds facilitates the problem of parallel running.

The tendency of generators to hunt may be minimized by surrounding the pole pieces of the field magnets with copper bands in which eddy currents are induced by the shifting and distortion of the field. These currents react on the field and oppose the shifting and thus damp the oscillations. A more suitable construction consists of a grid of copper embedded in the pole face. It is very seldom necessary to provide such "dampers" on pole pieces of generators for modern steam or water-wheel drive. They are usually necessary for gas-engine driven generators.

116. To Start a Single Alternator.—(1) See that there is plenty of oil in the bearings and that the oil rings are free to turn and that all switches are open. (2) Start exciter and adjust for normal voltage. Start generator slowly. See that the oil rings are turning. (3) Permit the machine to reach normal speed. Turn the generator field rheostat so that all its resistance is in the field circuit. Close the field switch. (4) Adjust the rheostat of the exciter for the normal exciting voltage. Slowly increase the alternator voltage to normal by cutting out the resistance of the field rheostat. (5) Close the main switch.

117. To Start an Alternator to Run in Parallel with Others.—(1) Bring the exciter and generator to speed as described in the above paragraph. Adjust the exciter voltage and close the field switch, the generator field resistance being all in. (2) Adjust the generator field resistance so that the generator voltage will be the same as the bus-bar voltage. (3) Synchronize, as outlined in one of the preceding paragraphs. Close the main switch. (4) Adjust the field rheostat until cross currents are a minimum (see Sec. **112**) and adjust the governors of the prime movers so that the load will be properly distributed between the operating units in proportion to their capacities. (5) Adjust the governor of the machine which is to take the most load so that it will admit more steam.

118. To Cut Out a Generator Which Is Running in Parallel with Others (Westinghouse Instruction Book).—(1) Preferably cut down the driving power until it is just sufficient to run the generator at no load. This will reduce the load on the generator. (2) Adjust the resistance in the field circuit until the armature current is at a minimum. (3) Open the main switch.

Caution.—The field circuit of a generator which is to be disconnected from the bus bars must not be opened before the main switch has been opened; for, if the field circuit is opened first, a heavy current will flow between the armatures.

119. Induction generators have the same construction as induction motors (see Sec. **142**). A revolving magnetic field is produced by the stator currents in exactly the same manner as in an induction motor (see Sec. **143**). Induction generators are made in two types as listed in Sec. **93.** The type in which the stator winding is the source of voltage is used for producing voltages of ordinary power frequencies, such as 25, 50, or 60 cycles. The type in which the rotor winding is the source of voltage is used for producing voltages of higher frequencies than ordinary power frequencies, such as 90, 100, 175, or 180 cycles. These higher frequencies are frequently required for the operation of high-speed portable tools and machines in the woodworking industry.

Induction generators, in which the stator windings are the source of voltage, have their stator windings connected to the electric system which is to receive the power and their rotor windings short-circuited as shown in Fig. 66. The machine cannot function as a generator until a revolving magnetic field is produced in the machine. The current which produces the rotating magnetic field must therefore be supplied to the stator winding from a source external to the machine. Therefore, an induction generator of this type must be operated in parallel with a synchronous generator. Such an induction generator is in effect an induction motor which is driven at a speed above the speed of its rotating magnetic field.

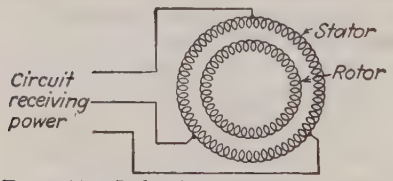


FIG. 66.—Induction generator connections.

Suppose an induction motor, which has a slip of 5 per cent at full load when operating as a motor, is driven at a speed 5 per cent greater than the speed of the rotating magnetic field. The flux cut by the rotor conductors will be practically the same as when it was operating as a motor. But the direction of motion of the conductors relative to the flux will be reversed. Hence the machine will become a generator and deliver power to the line approximately equal to its full-load motor rating. The frequency of the current supplied by an induction generator will always be the same as that of the synchronous generator with which it is in parallel. The induction generator tends to supply a leading current, just as does a condenser. The power factor at which it operates is determined by the slip and the design and is not dependent upon the load.

Induction generators in which the rotor is the source of voltage are used for the generators in motor-generator, frequency-changer sets. The

stator windings are connected to 25-, 50-, or 60-cycle main power supply, and the rotor supplies the power to the higher frequency circuits as shown in Fig. 67. If a 60-cycle current is passed into the primary winding of a standard wound-rotor motor and the motor is operated at synchronous or no-load speed, there is practically no voltage generated in the secondary. If, however, the rotor is held stationary, a 60-cycle voltage can be obtained from the secondary. If the rotor is revolved in the opposite

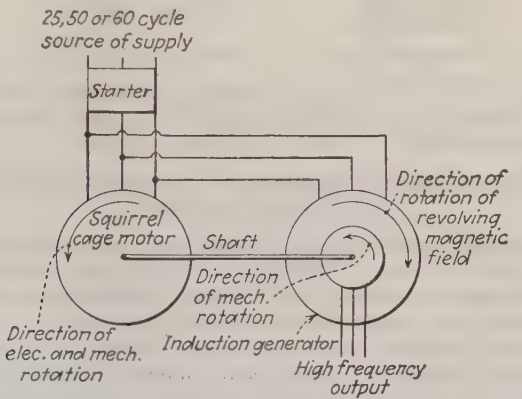


FIG. 67.—Schematic diagram of induction frequency-changer set.

direction to that in which it would revolve as a motor, a voltage of a frequency higher than 60 cycles is generated. The high frequency depends upon the speed and number of poles in the generator and can be calculated from the following formula:

$$\text{High frequency} = \frac{\text{poles} \times \text{r.p.m.}}{120} + \text{line frequency} \qquad (2)$$

The voltage delivered by the induction frequency changer depends upon the design of the primary and secondary windings, the speed of the set, and the applied primary voltage.

120. Inductor alternators are employed for the production of voltages of frequencies between 500 and 10,000 cycles for supplying the power to induction furnaces for the melting and heating of steel and alloys. The rotating element carries no electrical windings but consists simply of a toothed steel member (Fig. 68). The stationary member supports two sets of windings: the field windings and the armature coils. As the toothed member revolves, it varies the reluctance of the magnetic paths and thereby varies the flux produced by the current in the field windings. The flux also links with the armature coils, and its variation induces a voltage in these coils.

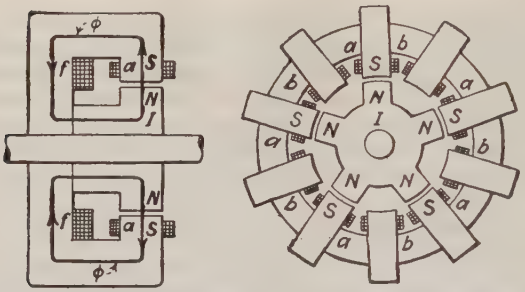


FIG. 68.—An inductor alternator. This type of construction has been used for relatively small alternators employed in radio transmission and gives as high as 200,000 cycles per sec. (*From Sanderson.*)

PRINCIPLES, CHARACTERISTICS, AND MANAGEMENT OF ELECTRIC MOTORS

121. Types of Electric Motors.—Electric motors are manufactured in a number of different types. They may be divided into three main groups, depending upon the type of electric system that they are designed to operate from: d-c; single-phase a-c; and polyphase a-c. There are several types of motors in each one of these groups, constructed so that they produce different starting and running characteristics. The principal types of electric motors are given in the following list:

Direct current.
  Shunt wound.
  Series wound.
  Compound wound.
Polyphase alternating current.
  Induction.
    Squirrel cage.
      Normal torque, normal starting current.
      Normal torque, low starting current.
      High torque, low starting current.
      Low torque, low starting current.
      High-resistance rotor.
      Automatic start.
      Multispeed.
    Wound rotor.
    Commutator, brush shifting.
    Polyspeed.
  Synchronous.
    Standard type.
    Fynn-Weichsel.
    Supersynchronous.

Single, phase, alternating current.
Repulsion.
Induction.
Shading-pole starting.
Inductively split-phase starting.
Capacitor type.
Repulsion start-induction run.
Repulsion induction.
Series.

122. Speed Classification of Motors.—Each electric motor possesses a certain inherent speed characteristic by means of which it can be classified in one of several groups. The following classification of speed characteristics is that adopted by The National Electrical Manufacturers' Association (N.E.M.A.).

1. A **constant-speed motor** is one whose speed is practically constant from no load to full load. Motors in this class may have an absolutely constant speed regardless of the load, or the speed may vary a few per cent from no load to full load.

2. An **adjustable-speed motor** is one in which the speed can be varied gradually over a considerable range but, when once adjusted, remains practically constant regardless of the load.

3. A **multispeed motor** is one which can be operated at any one of several definite speeds but, when once adjusted, remains practically constant regardless of the load. It differs from the adjustable-speed motor in that the multispeed motor can be operated at only certain definite speeds without any gradual adjustment of the speed between these definite speeds.

4. A **varying-speed motor** is one whose speed varies with the load, generally decreasing as the load increases.

5. An **adjustable varying-speed motor** is one in which the speed can be varied gradually over a considerable range, but in which the speed, when once adjusted for a given load, will vary in considerable degree with change in the load.

123. Service Classification of Motors.—Electric motors are classified into two groups depending upon the type of service they are designed for. **General-purpose motors** are those motors designed for general use without restriction to a particular application. They are designed to meet certain specifications as standardized by the National Electrical Manufacturers' Association. **Special-service motors** are those designed primarily to meet the requirements of special applications.

124. Brake motors are motors equipped with electrically controlled brakes as an integral part of the motor assembly. The brake motor manufactured by one company (see Fig. 69) consists of one or more rotating steel disks splined on a pinion on the motor shaft, with stationary

friction linings on each side of each disk. A helical spring in the center applies pressure to provide the required braking and either two, three, or four magnets, depending on the rating of the brake, supply force to compress the spring and release the brake while the motor is running.

When power is applied to the motor, the brake is immediately energized, since the brake leads are connected directly to the motor leads in the conduit box. The current energizes the magnets, and they pull the

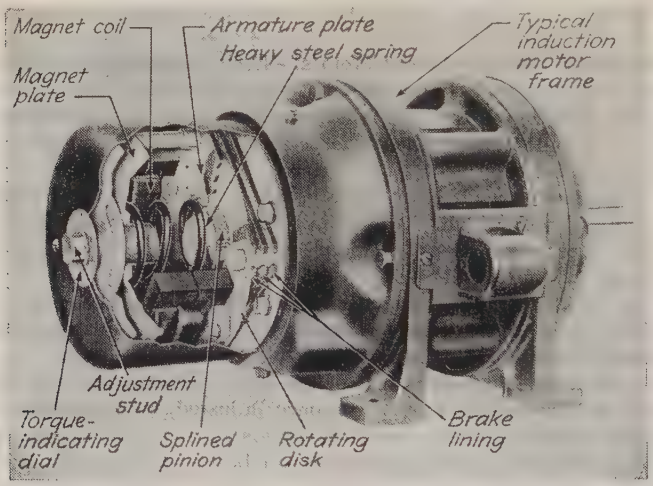


FIG. 69.—Brake motor, with brake cover partially cut away to illustrate the internal construction. (*General Electric Co.*)

armature plate toward the end plate. This removes the pressure on the revolving disks and allows them to move freely between the friction linings, releasing the brake.

Since the rotating disks are separated from the friction surfaces at all times except during actual braking, the motor delivers full rated horsepower at the output shaft.

When the motor is disconnected from the power supply, the magnets are immediately de-energized, and the spring pushes the armature plate away from the adjustable plate, toward the motor. This applies braking pressure on the surfaces between the revolving disks and the friction linings, bringing the motor to a quick smooth stop. This inherent smooth action, free from hammer blow, keeps stresses at the minimum in the brake and in belts, cables, gears, or chains through which the motor drives.

125. Gear motors are motors equipped with a built-in reduction gear as an integral part of the motor assembly (see Fig. 70). The motor itself

is generally an 1,800-r.p.m. machine. Output-shaft speeds between 2 and 1,550 r.p.m. are available. These motors can be obtained equipped with almost any type of general-purpose, polyphase induction; single-phase; or d-c motor.

Loads of the same horsepower and speed rating will require different gear sizes depending upon the type of load. The horsepower rating of

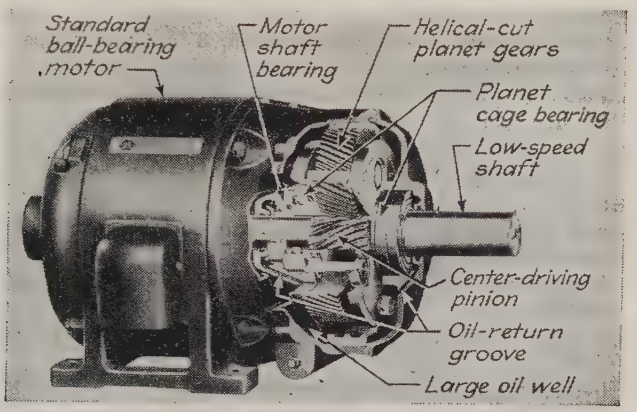


FIG. 70.—Typical gear motor for output speeds between 600 and 154 rpm. (*General Electric Co.*)

the gear should be equal to the horsepower rating of the motor times the proper service factor selected from the table below, depending upon the type of load and service.

Gear Service Factors

Character of load of driven machine	8 to 10 hr. service per day	24 hr. service per day
Uniform	1.00	1.25
Moderate shock	1.25	1.50
Heavy shock	1.75	2.00

Gear motors are available with three classes of gear-element construction in order to meet the different requirements of severity of service. They are classified as general purpose, special purpose, and heavy duty. The general-purpose gear motors are equipped with gears having a gear service factor of 1.0, the special-purpose motors having a gear service factor of 1.5, and the heavy-duty a gear service factor of 2.0

The following summary gives recommendations for applications of gear motors under operating conditions of good alignment, adequate attention and maintenance, and proper lubrication.

Satisfactory Service Conditions for Different Types of Gear Motors.

1. General purpose (service factor, 1).
   - *a.* 8 to 10 hr. per day continuous operation, infrequent starting, constant-torque load.
   - *b.* 24 hr. per day continuous operation, 3 to 4 months per year, infrequent starting, constant-torque load.
   - *c.* Frequent starting (normal-starting-torque motor) operating only few days per year (very intermittent service).
2. Special purpose (service factor, 1.5).
   - *a.* 24 hr. per day continuously, infrequent starting, constant-torque load.
   - *b.* 8 to 10 hr. per day continuously, frequent starting or moderately pulsating load.
   - *c.* Intermittent service, high-torque motor such as crane or hoist service.
   - *d.* 8 to 10 hr. per day, starting high-inertia load several times per day.
   - *e.* 8 hr. per day, infrequently reversing load.
   - *f.* 8 to 10 hr. per day with intermittent overloads (not stalling).
3. Heavy duty (service factor, 2).
   - *a.* 24 hr. per day continuously, with moderately pulsating load.
   - *b.* 24 hr. per day, frequent starting.
   - *c.* 8 to 10 hr. per day, reversing load with brake on motor.
   - *d.* Intermittent service, frequent reversing.
   - *e.* Intermittent service, frequently starting high-inertia loads or high-breakaway friction loads.
4. Extra-heavy duty (service factor, 2.5 to 5).

All applications requiring gears to meet conditions more severe than outlined under the above classifications should be referred to the manufacturer.

125A. Typical Speed-reducer Applications Grouped as to Character of Load

UNIFORM LOAD

Agitators:	Can-filling	Conveyors:	Feeders:
Liquid	machines	(Uniformly load-	Disk type
Semiliquid	Cookers:	ed or fed)	Elevators, bucket
Bleachers	Cereal	Apron	(uniformly load-
Blowers:	Fans (uniform speed	Assembly	ed or fed):
centrifugal or	and balance):	Belt	Centrifugal dis-
vane	Centrifugal	Oven	charge
Bottling machines	Propeller	Screw	

- Gravity discharge
- Continuous bucket
- Generators
- Kettles:
  - Brew
- Line shafts:
  - Light
- Machine tools:
  - Light
- Mash tubs
- Mixers
- Liquid
- Semiliquid
- Pumps:
  - Centrifugal
  - Geared
  - Rotary
- Screens:
  - Air washing
  - Traveling water, intake
- Textile machinery:
  - Cards

MODERATE SHOCK LOAD

- Beaters:
  - Pulp
- Blowers:
  - Lobe
- Car pullers
- Compressors:
  - Centrifugal or rotary
  - Reciprocating (3 or more cylinders)
- Conveyors:
  - (Heavy duty or dual drive, rough and non-uniform material)
  - Apron
  - Belt
  - Live roll
  - Screw
- Draw bench
- Driers:
  - Rotary
- Elevators:
  - Heavy-duty bucket
  - Freight
- Fans:
  - Large mine
  - Induced draft
- Feeders (pulsating loads):
  - Apron
  - Belt
  - Screw
- Hoists:
  - Reversing
  - Skip
- Kilns:
  - Cement
  - Lime
- Mills:
  - Ball
  - Pebble
  - Rubber sheet
- Mixers:
  - Dough
- Pumps:
  - Reciprocating (3 or more cylinders)
- Screens:
  - Rotary, gravel or stone
- Stock chests
- Stokers
- Textile machinery:
  - Looms
- Wire-drawing machines:
  - (Individual)

HEAVY SHOCK LOAD

- Compressors:
  - Reciprocating (single or two cylinder)
- Conveyors:
  - Reciprocating
  - Shaker
- Crushers:
  - Ore
  - Stone
- Dredge cutter head
- Feeders:
  - Reciprocating
- Hoists, mine
- Jordans:
  - Mills
  - Hammer
  - Rod
  - Rubber calender
- Pumps:
  - Reciprocating (single or two cylinder)
- Punch presses

126. Direction of Mounting of Motors. –The standard type of motor is designed to be mounted with its shaft horizontal. Motors can be obtained, however, for mounting with their shafts vertical, but they are more expensive and require more careful attention.

127. Bearings for motors may be of the sleeve or ball-bearing type. The type to use is largely one of individual preference, since both types when properly designed and maintained will give satisfactory service. Most manufacturers are prepared to furnish from regular stock either with sleeve or ball bearings any type of motor up to 200 hp. except some totally enclosed motors. Motors of the larger sizes generally are furnished with sleeve bearings.

For especially quiet operation, sleeve bearings are preferable.

The application of grease-packed ball bearings is especially advantageous under the following conditions:

1. Where the motor frame does not remain in a stationary position after installation.

2. Where the motor is located in an inaccessible place.
3. For many totally enclosed motor applications.
4. For motors with their shafts mounted vertically.
5. For high speeds.
6. For heavy thrust loads.

The cost of ball-bearing-equipped motors is slightly more than for sleeve-bearing motors.

128. Types of Motor Enclosure.—The different types of electric motors may be obtained with constructions which give different degrees of enclosure and protection to the operating parts and windings. The different standard types as explained and defined by the American Standards Association are given below.

A **self-ventilated machine** is one which has its ventilating air circulated by means integral with the machine.

A **separately ventilated machine** is one which has its ventilating air supplied by an independent fan or blower external to the machine.

An **enclosed self-ventilated machine** is a machine having openings for the admission and discharge of the ventilating air, which is circulated by means integral with the machine, the machine being otherwise totally enclosed. These openings are so arranged that inlet and outlet ducts or pipes may be connected to them.

NOTE.—Such ducts or pipes, if used, must have ample section and be so arranged as to furnish the specified volume of air to the machine; otherwise the ventilation will not be sufficient.

An **enclosed separately ventilated machine** is a machine having openings for the admission and discharge of the ventilating air, which is circulated by means external to and not a part of the machine, the machine being otherwise totally enclosed. These openings are so arranged that inlet and outlet duct pipes may be connected to them.

An **open machine** is a self-ventilated machine having no restriction to ventilation other than that necessitated by mechanical construction.

NOTE.—In the sense of this definition an open machine, when the term is used without qualification, is understood not to be splashproof or dripproof.

A **totally enclosed machine** is one so enclosed as to prevent exchange of air between the inside and the outside of the case, but not sufficiently enclosed to be termed airtight.

A **totally enclosed fan-cooled machine** is a totally enclosed machine equipped for exterior cooling by means of a fan or fans, integral with the machine but external to the enclosing parts.

A **protected machine** is one in which all ventilating openings in the frame are protected with wire screen, expanded metal, or perforated covers, the openings in which do not exceed ½ sq. in. (323 sq. mm.) in

area and are of such shape as not to permit the passage of a rod larger than $\frac{1}{2}$ in. (12.7 mm.) in diameter, except that where the distance of exposed live parts from the guard is more than 4 in. (101.7 mm.) the openings may be $\frac{3}{4}$ sq. in. (484 sq. mm.) in area and must be of such shape as not to permit the passage of a rod larger than $\frac{3}{4}$ in. (19 mm.) in diameter.

A **semiprotected machine** is one in which part of the ventilating openings in the frame, usually in the top half, are protected, as in the case of a "protected machine," but the others are left open.

A **dripproof machine** is one in which the ventilating openings are so constructed that drops of liquid or solid particles falling on the machine at any angle not greater than 15 deg. from the vertical cannot enter the machine either directly, or by striking and running along a horizontal or inwardly inclined surface.

A **splashproof machine** is one in which the ventilating openings are so constructed that drops of liquid or solid particles falling on the machine or coming toward it in a straight line at any angle not greater than 100 deg. from the vertical cannot enter the machine either directly or by striking and running along a surface.

An **explosion-proof machine** is one in an enclosing case which is designed and constructed to withstand an explosion of a specified gas or dust which may occur within it, and to prevent the ignition of the specified gas or dust surrounding the machine by sparks, flashes, or explosions of the specified gas or dust which may occur within the machine casing.

A **waterproof machine** is a totally enclosed machine so constructed that a stream of water from a hose (not less than 1 in. in diameter) under a head of 35 ft. and from a distance of about 10 ft. can be played on the machine without leakage, except that leakage which may occur around the shaft may be considered permissible, provided it is prevented from entering the oil reservoir and provision is made for automatically draining the machine.

NOTE.—The machine should be provided with a check valve for drainage or with a tapped hole at the lowest part of the frame which will serve for application of drain pipe or drain plug.

A **dusttight machine** is one so constructed that the enclosing case will exclude dust.

A machine is designated as **moisture resistant, fume resistant,** etc., when so constructed, protected, or treated that it will not be readily injured when subjected to the specified material, as follows:

1. Moisture (very damp or humid atmosphere such as occurs in dye-houses, evaporating rooms, certain tropical localities and in some mines).
2. Fumes (as may be specified).
3. Gas (as may be specified).

4. Acid (as may be specified).
5. Alkali (as may be specified).

A **submersible machine** is one so constructed that it will operate successfully when submerged in water under specified conditions of pressure and time.

129. Torques of Motors.—The *starting or static torque* (locked-rotor torque) of a motor is the turning effort exerted by the motor at standstill at the instant that the motor is connected to the line. It is the turning effort that will be exerted in starting a load from rest.

The *pull-up torque* of a motor is the minimum turning effort developed by the motor during the period of acceleration from rest to full speed.

The *breakdown torque* of a motor is the maximum turning effort that the motor will develop when running, without a sudden drop in the speed and stalling of the motor.

The *pull-in torque* of a synchronous motor is the maximum turning effort that the motor will exert to pull its connected inertia load into synchronism.

The *nominal pull-in torque* of a synchronous motor is the turning effort which the motor will exert when operating as an induction motor at 95 per cent of synchronous speed.

The *pull-out torque* of a synchronous motor is the maximum sustained turning effort which the motor will exert at synchronous speed for 1 min.

The *rated torque* of a motor is the turning effort exerted by the motor when delivering its rated horsepower load at rated speed.

The *maximum torque* of a motor is the maximum turning effort that the motor can exert. In some motors this maximum torque is developed under standstill conditions and in others at some definite speed.

All the above torque conditions are dependent upon rated impressed voltage and, also, for a-c motors are dependent upon rated frequency.

130. The rating of an electric motor includes the service classification (Sec. **123**), voltage, full-load current, speed, number of phases and frequency if alternating current, and full-load horsepower.

The horsepower rating which is stamped on the motor name plate by its manufacturer is the horsepower load which the motor will carry without injury to any part of the motor.

In any motor a certain amount of the input energy is lost in the machine. This energy that is lost in the machine itself is dissipated in the form of heat, which raises the temperature of the motor. As the load on a motor is increased the losses increase, and, therefore, the temperature of the different parts of the machine increase with the load. If too great a load is put on the motor, the motor will become excessively hot, with probable injury to the insulation of the windings.

The different types of insulation employed in the construction of motors, together with their maximum safe operating temperatures, are given in the following table:

Insulating Materials for Electrical Machinery

Class	Description of material	Max. safe operating temperature, °C.
O	Class O insulation consists of cotton, silk, paper, and similar organic materials when neither impregnated[a] nor immersed in oil	90
A	Class A insulation consists of cotton, silk, paper, and similar organic materials when impregnated[a] or immersed in oil; also enamel as applied to conductors	105
B	Class B insulation consists of mica and asbestos and similar inorganic materials, in built-up form combined with binding cement. If Class A material is used in small quantities for structural purposes only, in conjunction with Class B insulation, the combined materials may be considered as Class B, provided the electrical and mechanical properties of the insulated winding are not impaired by the application of the temperature permitted for Class B material. (The word "impair" is used here in the sense of causing any change which could disqualify the insulating material for continuous service)	125
C	Class C insulation consists of inorganic materials such as pure mica, porcelain, quartz, etc.	No limit yet set

[a] Impregnated cotton, paper, or silk: An insulation is considered to be "impregnated" when a suitable substance replaces the air between its fibers, even if this substance does not completely fill the spaces between the insulated conductors. The impregnating substance, in order to be considered suitable, must have good insulating properties, must entirely cover the fibers and render them adherent to each other and to the conductor, must not produce interstices within itself as a consequence of evaporation of the solvent or through any other cause, must not flow during the operation of the machine at full working load or at the temperature limit specified, and must not unduly deteriorate under prolonged action of heat.

Since it is generally not possible to measure the temperature of the hottest spot in the machine, the maximum observable temperature must be somewhat less than the maximum safe operating temperature of the hottest spot. The values given in the following table are in accordance with the standardized conventional allowances between hottest-spot temperatures and maximum observable temperatures.

Maximum Safe Observable Temperatures

Method	Class O material, deg. C	Class A material, deg. C	Class B material, deg. C
Thermometer method	75	90	110
Resistance method	80	95	115
Embedded-detector method	85	100	120

The horsepower ratings of motors are based on an observable safe temperature rise above the temperature of the surrounding air. The temperature of the surrounding air is called the ambient temperature and is taken as 40°C. If a motor is given a certain horsepower rating on a 55°C. basis, the manufacturer guarantees that the motor will deliver its rated horsepower when operating under rated voltage, frequency, and surrounding temperature conditions without the observable temperature of its windings exceeding a temperature of 40°C. (ambient temperature) + 55°C. (temperature rise) = 95°C.

Two different methods are employed for the rating of electric motors: continuous rating and intermittent rating. The allowable rating of a given motor is determined by the continuity of operation. Obviously, a motor can be rated higher for intermittent service than for continuous service; conversely, a motor rated for intermittent service must not be used at the same rating for continuous duty. General-purpose motors are always rated on a continuous-duty basis.

Motors for intermittent duty are given a short-time rating. The standard duration of tests for these ratings is 5, 15, 30, and 60 min. A motor rated at a certain horsepower for 30 min. will carry its rated load continuously for a period of 30 min.

All motor ratings are based on a specified temperature rise when operating at full load in an ambient temperature of 40°C. General-purpose open motors are given a continuous rating for 40°C. temperature rise. Motors so rated when operated at rated voltage and frequency will carry their rated load continuously without the observable temperature of its windings exceeding a temperature rise of 40°C. above their surrounding atmosphere. This rating provides a considerable factor of safety in order to allow for the usual variations in operating conditions. Motors rated on the 40°C. temperature-rise basis will carry their rated load continuously without injury to any part of the machine under the following service conditions, which are defined as usual:

1. An ambient temperature not exceeding 40°C.
2. A variation in voltage of not more than 10 per cent above or below the name-plate rating.
3. A variation in frequency of not more than 5 per cent above or below the name-plate rating.
4. A combined variation of voltage and frequency of not more than 10 per cent above or below the name-plate rating, provided that the frequency does not exceed 5 per cent variation.
5. An altitude not exceeding 1,000 m. (3,300 ft.).
6. Location or atmospheric conditions as to dust, moisture, or fumes which will not seriously interfere with the ventilation of the motor.
7. Solid mounting and all belt and chain drives and gearing.

A 40°C. temperature-rise-rated motor will carry momentarily an overload of 50 per cent in excess of its rated load. Most 40°C. motors

will carry 1.15 times their rated load continuously when operated at rated voltage and frequency in an ambient temperature of 40°C. The factor of 1.15 is known as a service factor. If this service factor is allowable it should be marked by the manufacturer on the name plate.

The following types of motors when provided with Class A insulation are rated on a 50°C. temperature-rise basis and when provided with Class B insulation are rated on a 70°C. temperature-rise basis:

1. Protected.
2. Semiprotected.
3. Dripproof.
4. Splashproof.

The following types of motors when provided with Class A insulation are rated on a 55°C. temperature-rise basis and when provided with Class B insulation are rated on a 75°C. temperature-rise basis:

1. Totally enclosed.
2. Totally enclosed, fan cooled.
3. Explosion-proof.
4. Waterproof.
5. Dusttight.
6. Submersible.

Motors rated on the 50, 55, 70, and 75°C. temperature-rise basis do not have any service factor.

When a motor is operated in an ambient temperature in excess of 40°C. the allowable load on the motor must be reduced from its rated value a sufficient amount so that the maximum observable temperature of its windings as given in the above table will not be exceeded.

131. Starting Currents of Motors.—In stating the starting current taken by a motor it should be specified just what current is meant, as starting currents are given in several different ways. In some cases the starting current pulled from the line is not the same as the current flowing into the motor itself at the instant of starting. If the rotating member of a motor is held stationary (blocked rotor) and voltage applied to the machine a certain current would be indicated. This current is the first inrush current that will occur at starting. If the starting current is measured with a well-damped ammeter under actual starting conditions (rotor free to revolve), the current indicated on the ammeter will be less than the first inrush current. This is true owing to the fact that the ammeter does not have a chance to indicate the peak current before the motor has started to revolve and the current has decreased somewhat. It is standard practice to take the free-rotor value of starting currents as 75 per cent of the blocked-rotor values.

The **blocked-rotor current of a motor** is the current taken directly by the motor with the revolving part held stationary.

The **blocked-rotor current of a motor and its starter** is the current taken from the line with the revolving part held stationary.

The **free-rotor current of a motor** is the maximum current taken directly by the motor during the starting period as indicated by a well-damped ammeter.

The **free-rotor current of a motor and its starter** is the maximum current drawn from the line during the starting period as indicated by a well-damped ammeter.

The average starting current of a motor is the average value of the starting current that must be considered in selecting fuses or circuit breakers. Fuses with a rating equal to the average starting current of a motor will allow the starting of the motor without rupturing the fuses. Owing to the time-lag characteristic of fuses, the peak value of the starting current will not rupture fuses of a rating considerably less than the peak value of the starting current.

132. Permissible Motor-starting Currents.—The operating conditions of an electric power system are affected by the currents taken by motors under starting conditions. Excessive power fluctuations will cause large changes in the voltage of the system and excessive voltage drops under the peak current conditions. These power and voltage fluctuations may result in unsatisfactory operating conditions for one or more of the following reasons:

1. Actuation of undervoltage protective or release devices on motor controllers, causing shutdown of motors.
2. Stalling of induction motors that are operating close to full load or slightly over full load.
3. Objectionable dips in light output of lamps and flickering of lamps.
4. In the case of small private generating plants, danger of overloading of generators.

Each electric power company has definite rules with respect to permissible starting currents for motors supplied from their system. At the present time, there is no standardization of these rules, each power company having its own set of rules. Some of these rules limit the starting current on a basis of allowable percentage of full-load current of the motor. With one of the newer rules, which is called the increment method, the maximum starting current of any motor must not be greater than a certain number of amperes per kilowatt of maximum-demand load of the customer.

133. The speed regulation of a motor is the percentage drop in speed between no load and full load based on the full-load speed.

$$\text{Per cent speed regulation} = \frac{\text{no-load speed} - \text{full-load speed}}{\text{full-load speed}} \times 100 \quad (3)$$

134. Direct-current Motors.—All d-c motors must receive their excitation from some outside source of supply. Therefore, they are always separately excited. The interconnection of the field and armature windings may be made, however, in one of the three different ways

employed for self-excited, d-c generators. A d-c motor may be designed, therefore, to operate with its field connected in parallel or in series with its armature, producing, respectively, a shunt or series motor. If the machine is provided with two field windings, one connected shunt and the other series, it is a compound motor. The speed of a shunt motor connected directly to the line is nearly constant from no load to full load, while the speed of a series motor drops off rapidly as the load is increased. If a series motor were operated at no load with normal voltage, it would attain a dangerous speed, so high in most cases that it would throw itself apart by centrifugal force. A series motor should never be operated at no load, unless there is sufficient external resistance connected in series with the motor to limit its speed to a safe value. For this reason a belt drive should never be used with a series motor.

Standard compound motors are designed to operate with the shunt and series fields connected so as to aid each other (cumulative). They, therefore, have operating characteristics that are a compromise between those of the shunt and series motors. Their speed drops off considerably as the load is increased, but not nearly so much as with the series motor. The compound motor will not run away under no load. The amount of change of speed from no load to full load depends upon the strength of the series field. The stronger the series field is, the greater the change in speed from no load to full load. Special compound motors with their field windings connected so as to buck each other (differential) are used sometimes for special applications. If the series field is of just the proper strength, a differential compound motor will operate at a more constant speed than a shunt motor, but it tends to be unstable under overload conditions.

135. Torque Characteristics of D-c Motors.—The torque developed by any one of the three types of d-c motors, either at starting or while running, depends upon the product of the magnetic flux and the armature current. Since in a shunt motor the flux is nearly constant at all times, the torque varies nearly directly with the value of the armature current. In a series motor the armature current flows directly through the field winding so that the flux is not constant but varies almost directly with the value of the armature current. The torque of a series motor, therefore, varies approximately as the square of the armature current. Doubling the armature current will make the torque four times as great. The cumulative compound motor has a torque characteristic that is a compromise between that of the series motor and that of the shunt motor. The torque will increase faster than the increase in armature current but not so fast as the square of the armature current. In just what way the torque varies with the armature current for a cumulative compound motor depends upon the relative strength of the series and shunt fields. The curves of Fig. 71 indicate the relation between torque and armature current for the different types of d-c motors.

The maximum value of starting torque that it is satisfactorily possible for any d-c motor to produce is limited only by the commutating conditions. This usually limits the current to approximately 200 per cent of full-load current for a shunt motor and 250 per cent of full-load current for a series or compound motor. The corresponding torques are approximately 200 per cent of full-load torque for a shunt motor, 300 per cent for a compound motor, and 400 per cent for a series motor.

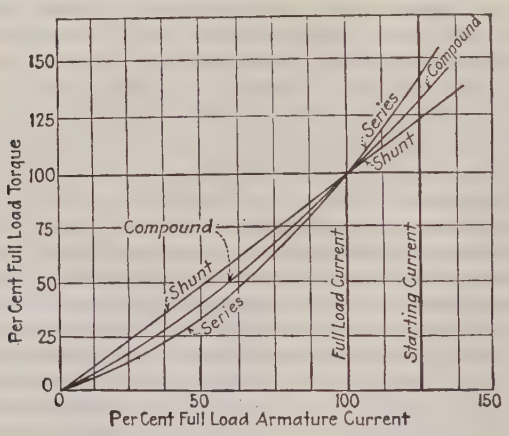


FIG. 71.—Torque characteristics of d-c motors.

There is no value of pull-out torque for a d-c motor. If the load on a d-c motor was continually increased, the motor would gradually slow down as the load increased, until finally the load would become so great that the motor would gradually stop. Of course, it would never be feasible in practice to overload the machine to such extent that it would stop, and long before such a load was reached the fuses in the circuit would blow.

136. Method of Starting D-c Motors (*The Electric Controller & Manufacturing Company*).—A d-c motor of any capacity, when its armature is at rest, offers a very low resistance to the flow of current, and an excessive and perhaps destructive current would flow through it if it were connected directly across the supply mains while at rest. Consider a motor adapted to a normal full-load current of 100 amp. and having a resistance of 0.25 ohm; if this motor were connected across a 250-volt circuit, a current of 1,000 amp. would flow through its armature; in other words, it would be overloaded 900 per cent, with consequent danger to its windings and also to the driven machine. In the case of the same motor, with a rheostat having a resistance of 2.25 ohms inserted in the motor circuit, at the time of starting the total resistance to the flow of current would be the resistance of the motor (0.25 ohm) plus the

resistance of the rheostat (2.25 ohms), or a total of 2.5 ohms. Under these conditions exactly full-load current, or 100 amp., would flow through the motor, and neither the motor nor the driven machine would be overstrained in starting. This indicates the necessity of a rheostat for limiting the flow of current in starting the motor from rest.

An electric motor is simply an inverted generator or dynamo, consequently when its armature begins to revolve a voltage is generated within its windings just as a voltage is generated in the windings of a generator when driven by a prime mover. This voltage generated within the moving armature of a motor opposes the voltage of the circuit from which the motor is supplied, and hence is known as a counter-e.m.f. The net voltage tending to force current through the armature of a motor when the motor is running is, therefore, the line voltage minus the counter-e.m.f.

In the case of the motor above cited, when the armature reaches such a speed that a voltage of 125 is generated within its windings, the effective voltage will be 250 minus 125, or 125 volts, and, therefore, the resistance of the rheostat may be reduced to 1 ohm without the full-load current of the motor being exceeded. As the armature further increases its speed, the resistance of the rheostat may be further reduced until, when the motor has almost reached full speed, all the rheostat may be cut out, and the counter-e.m.f. generated by the motor will almost equal the voltage supplied by the line so that an excessive current cannot flow through the armature.

It is general practice to provide a rheostat for starting a d-c electric motor, except for small fractional-horsepower motors of ¼ hp. or smaller. In special cases, when the motor is started very infrequently and the starting load is light, larger motors may be started by throwing them directly across the line. Motors as large as 5 hp. have been successfully started in this way, but the manufacturer should be consulted whenever one contemplates starting a motor larger than 1 hp. by this method. The resistor providing the starting resistance is divided into sections and is so arranged that the entire length or maximum resistance of the rheostat is in circuit with the motor at the instant of starting and that the effective length of the resistance conductor, and hence its resistance, may be reduced as the motor comes up to speed.

In cutting out the resistance of a starting rheostat care must be used not to cut it out too rapidly. If the resistance is cut out more rapidly than the armature can speed up, a sufficient counter-e.m.f. will not be generated to properly oppose the flow of current, and the current will be excessive.

The standard starting rheostat, when thrown into the first position, limits the armature current to about 150 per cent of the full-load current. This current will produce a starting torque of about 150 per cent of full-load torque for a shunt motor, of about 175 per cent for a standard cumu-

lative compound motor, and of about 225 per cent for a series machine. If greater starting torque is required, it can be obtained by advancing the starter to the second or third point. The allowable starting torque that can be obtained in this way is limited by commutating conditions to about 200 per cent of full-load torque for a shunt motor, to 300 per cent for a compound motor, and to 400 per cent for a series motor. The currents corresponding to these maximum allowable torques are approximately 200 per cent of full-load current for a shunt motor, 250 per cent of full-load current for a cumulative compound motor, and 250 per cent of full-load current for a series motor.

137. Speed Control of D-c Motors.—The speed of d-c motors for a given load may be controlled by the following methods:

1. Armature control.
   a. Variable resistance in series with armature.
   b. Variable-voltage generator supplying armature (Ward-Leonard system).
   c. Variable voltage supplied to armature by controlled electronic rectifier.
   d. Resistance shunted across armature.
2. Field control.
   a. Shunt-field rheostat.
   b. Variable-voltage generator supplying shunt field.
   c. Variable voltage supplied to shunt field by controlled electronic rectifier.
   d. Resistance shunted across series field.
3. Combination of armature and field control.

138. Armature Speed Control.—Any d-c motor may have its speed reduced below normal by armature control. With this method, the speed is controlled by varying the voltage impressed upon the armature, while the voltage of the field is held constant. For a constant torque load, the speed will vary in approximate proportion to the voltage impressed on the armature. The allowable horsepower output will decrease proportionally to the decrease in speed.

Armature speed control may be obtained by inserting an external variable resistance in series with the armature circuit. The location of such a resistance for the different types of d-c motors is shown in Fig. 71*A*. This method is easy to apply and requires only simple and relatively inexpensive equipment, and gradual control of the speed down to practically zero speed can be obtained. Series armature resistance control, however, has the following objections:

1. **Bulk of Rheostat.**—This may not be very objectionable if only a few motors are so controlled, but for a number the extra space becomes a factor, and in many cases it is difficult to find sufficient room near the motor.

2. **Inefficiency of the System.**—The same amount of power is supplied at all speeds, but at low speeds only a small part of it is converted into useful work, the balance being wasted in the rheostat as heat.

3. **Poor Speed Regulation with Varying Loads.**—Since the impressed voltage at the armature terminals is equal to the line voltage minus the resistance drop in the rheostat ($V_t = V - I_a R_x$), any change in the current drawn by the motor produces a change in the terminal voltage, the counter-e.m.f. and therefore the speed.

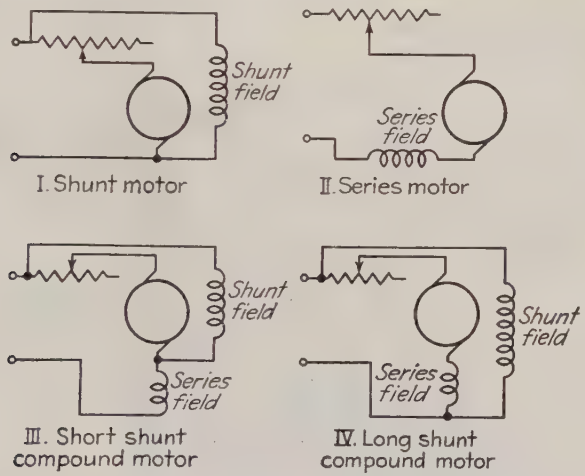


FIG. 71A.—Speed control with armature resistance.

Armature series resistance control is the type of speed control most commonly employed for series motors. Series motors requiring speed control are used chiefly for intermittent duty, and the total loss of energy in the control resistance is therefore not so great as it would be for continuous duty. Generally, armature series resistance control is not employed for shunt and compound motors, unless a wider speed range is desired than can be obtained satisfactorily by means of field control or unless very low speeds are required.

Armature speed control obtained by a variable-voltage generator (Ward-Leonard system) requires an individual motor generator set for each motor whose speed is to be controlled. Although this method is applicable to any type of d-c motor, it is most commonly used with shunt or compound motors. A schematic diagram is given in Fig. 71*B*. The Ward-Leonard system gives very close control of the speed over a wide range but has the disadvantage of requiring three full-sized machines for each motor drive. For automatic drive control with d-c motors, a variation of the Ward-Leonard system may be used, employing control generators (see Secs. **41A** to **41C** and Sec. **140B**).

The variable voltage for armature control may be obtained from a controlled electronic rectifier (see Sec. **48** of Div. 6). For very small fractional-horsepower motors, triode vacuum tubes can be employed for the rectification. The average voltage input to the motor armature is controlled by variation of the grid voltage of the tubes. Varying the grid voltage will vary the anode-to-cathode voltage drop of the tube and thereby vary the voltage impressed on the motor armature. For motors of any appreciable size, a vacuum-tube rectifier would be inefficient, since

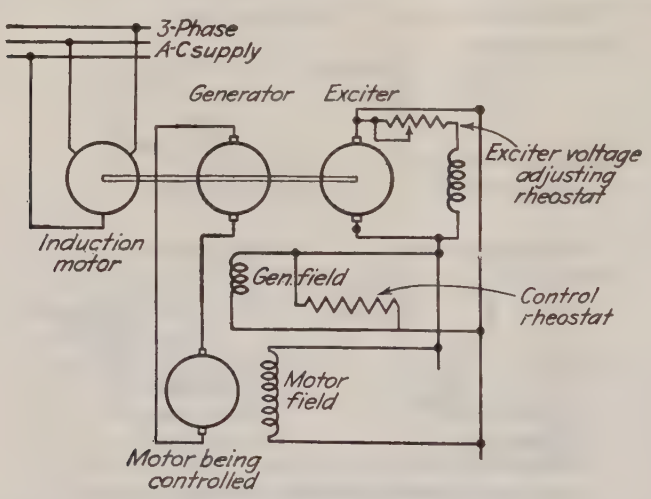


FIG. 71*B*.—Ward-Leonard system of speed control.

the power consumed by the tubes of the rectifier would be proportional to the reduction in speed obtained. Also the current-carrying capacities of vacuum tubes would be sufficient only for very small motors. For small and medium-sized motors, thyratron tubes would be used, and ignitron tubes would be used for medium and large-sized motors. With both thyratron and ignitron rectifiers, the average voltage imput to the motor armature would be controlled by controlling the period of conduction of the tubes. (see Secs. **29** and **34** of Div. 6). A circuit for electronic speed control of a shunt motor is shown in Fig. 71*C*. Electronic armature speed control gives close control of the speed over a wide range. Electronic control of d-c motor speed can be adapted for automatic drive control (see Sec. **140A**).

Resistance shunted across the armature is useful for controlling the speed of d-c motors to very low values at light loads. It is used only in conjunction with series armature-resistance control. Connections for this method are shown in Fig. 71*D*.

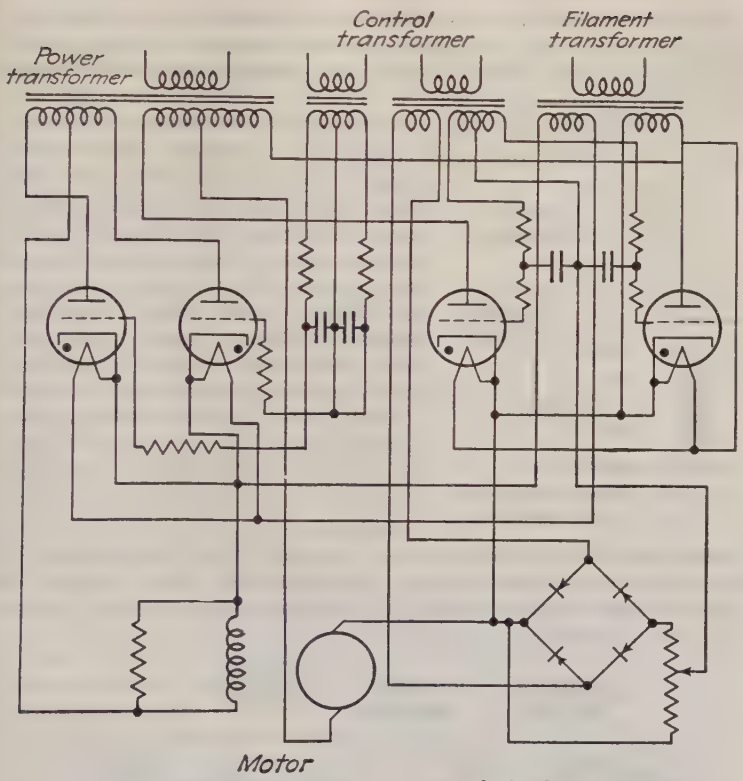


FIG. 71*C*.—Electronic control of speed of a d-c motor.

139. Field Speed Control.—The speed of d-c motors may be controlled by varying the field current of the motor while the armature voltage is held constant. Reducing the field current will reduce the flux and consequently increase the speed of the motor. Field control gives close control of the speed over a limited range. The speed of any shunt motor may be increased approximately 25 per cent above normal by field control. Where greater speed range than this is required, a shunt motor designed for adjustable-speed service should be used. A speed range of 4:1 is the practical limit for field control with an adjustable-speed shunt motor. The simplest method of obtaining field speed control for shunt or compound motors is by means of a field rheostat connected in series with the shunt field. The proper location of a field rheostat in motor circuits is shown in Fig. 71*E*. This method is the one most commonly used for speed control of shunt and compound motors. It is

very easy to apply, requires simple and inexpensive equipment that occupies only a very small space, does not consume any appreciable amount of power in the control equipment, and gives good speed regulation with varying loads.

Field control of shunt or compound motors may be obtained by energizing the shunt field from a variable-voltage generator. This method requires an individual motor generator set for each motor to be controlled and has no advantage over the simple field rheostat method except for automatic drive control of small motors requiring only limited speed range. When employed in automatic drive control, the shunt field of the motor is excited by a control generator (see Secs. **41A** to **41C**).

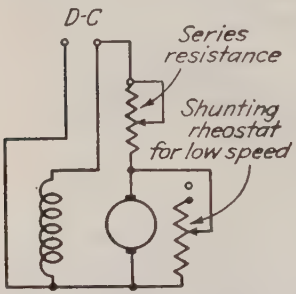


FIG. 71*D*.—Speed control using shunt across armature.

Field control of shunt and compound motors is sometimes obtained by supplying the shunt field from a controlled electronic rectifier. The fundamental principles and connections of the controlled rectifier are the same as those discussed for the rectifiers employed for electronic armature control. Electronic field control generally is employed only in combination with electronic armature control, where very wide speed range is required.

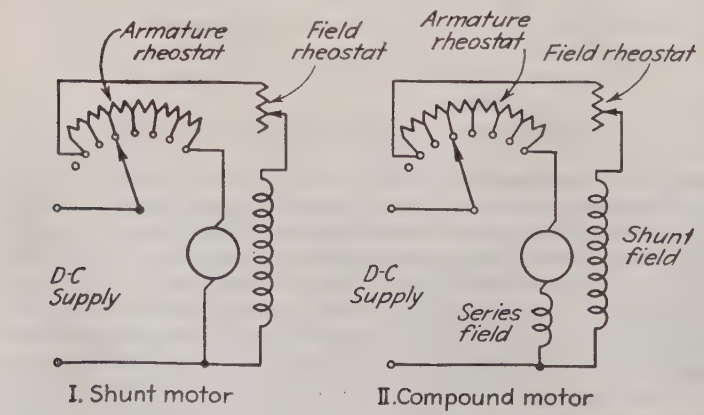


FIG. 71*E*.—Control of speed with field rheostat.

Field control of series motors is obtained by shunting a resistance across the series field. If a resistance or rheostat is placed in parallel with the field of a series-wound motor, the speed will be increased instead of

decreased at a given load. This is known as shunting the field of the motor. This shunt would never be applied till the motor has been brought up to normal full speed by cutting out the starting resistance. With a "shunted field" a motor drives a load at a speed higher than normal and therefore requires a correspondingly increased current. With a shunted field more current is required to produce a given torque. The allowable torque at speeds above normal is, therefore, less than the rated full-load torque. With this type of speed control the motor is practically a constant-horsepower machine, the allowable rating being practically the same for all speeds.

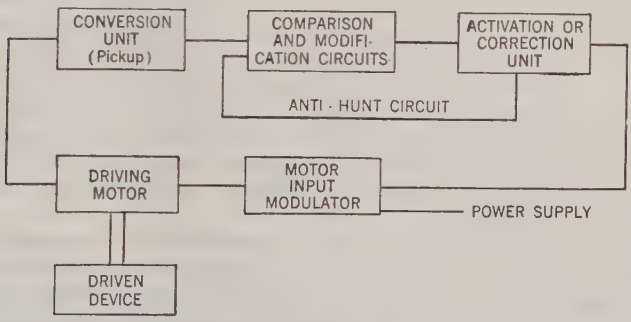


FIG. 71*F*.—Block diagram of elements for automatic drive control.

139A. Combination of armature and field control is employed where wide speed range is required. The following combinations are frequently employed:

1. Armature resistance combined with shunt-field rheostat.
2. Ward-Leonard system combined with shunt-field rheostat.
3. Electronic armature control combined with electronic field control.

A common combination, which is used for controlling the speed of standard constant-speed motors, is to employ armature control for reducing the speed to 50 per cent below normal and to use field control for increasing the speed 25 per cent above normal.

140. Automatic drive control (servo systems) is the automatic control of a motor to meet specified requirements of the driven equipment or material. A few of the more common requirements that are automatically fulfilled by automatic drive control are:

1. Production of uniform acceleration and deceleration.
2. Maintenance of constant speed regardless of load, and control of speed over wide speed range.
3. Production of constant torque over wide speed range.

The essential elements of an electric-drive control system are shown in the block diagram of Fig. 71*F*. An electric-drive control system must have the ability (1) to pick up a signal whenever there is a deviation from

the required performance of a driven machine or process, (2) to convert this variation signal into a proportional electrical signal, (3) to compare this electrical signal with the desired standard, (4) to have the deviation from the standard activate a correction in the electrical input to the drive motor, and (5) to provide antihunting characteristics.

Requirements (1) and (2) above are fulfilled by the conversion element (pickup) of Fig. 71*F*. The conversion element may take a variety of forms. It may be a pilot generator coupled to the drive motor or driven machine, which will pick up any variation in speed and translate this speed variation into a proportional voltage variation. It may be a resistor in series with the armature of the drive motor. The voltage across such a resistor will act as a pickup for any variation in the current delivered to the motor. Such a pickup may be used for constant torque control of a motor. Phototubes are used in many cases as the pickup device. A phototube circuit will pick up and convert into a voltage any deviation from the proper position of a machine tool or of a driven object. The pickup device may be a set of synchros, which will pick up and convert into a signal voltage any deviation from a desired angular position (see Sec. **170A**).

Requirement (3) of the control system is fulfilled by the comparison circuit of Fig. 71*F*. For example, consider the conditions for automatic speed control of a motor. The voltage of the conversion element (a pilot generator) is connected in series with a standard voltage, and any variation in the voltage of the pilot generator results in a variation of current in the comparison circuit. This variation in current will be controlled in magnitude and direction by the variation in the voltage of the pilot generator. The output of the comparison circuit may not be great enough to produce the proper functioning of the activation circuit. In these cases, a modification circuit, which will consist of an electronic amplifying circuit, must be employed. Often it is desired that the controlled machine be influenced by some other factor or factors in addition to the main controlling function. Such requirements are fulfilled by means of modification circuits.

Requirement (4) of the control system is fulfilled by the activation circuit of Fig. 71*F*. The output of the comparison and modification circuit must be connected to an activation circuit, which will control the input circuit to the drive motor in such a manner as to correct the deviation of the driven device. For example, the output of the comparison circuit may act upon the grid-control circuit of a thyratron rectifier and in this manner control the input to the drive motor.

Requirement (5) of the control system is fulfilled through coupling or feedback circuits between comparison and activation circuits. The purpose of these antihunt circuits is to prevent overshooting of the correction and to prevent serious oscillations about the desired controlled condition. Although these antihunt circuits are in many cases essential, a discussion of them is beyond the scope of this book.

Since most types of a-c motors do not lend themselves to convenient control of their performance characteristics, d-c motors usually are employed where drive control is desired. In the majority of drive-control applications, the requirements are met through the use of d-c motors controlled by electronic or electrodynamic control systems. In both these control systems, the d-c motor performance is controlled through (1) control of input to the motor armature, (2) control of input to the motor field, or (3) combination control of input to the motor armature and field. In the electronic control systems, the motor input is adjusted by means of controlled vacuum, thyratron, or ignitron rectifiers. In the electrodynamic control systems, the motor input is adjusted by means of control generators (see Sec. **41A**). In many cases, electronic and electrodynamic control systems are competitive methods. In the electrodynamic control systems, electron tubes often are employed as a part of the system for amplifying or other modification purposes.

140A. In electronic control of d-c motors, either or both the armature and field are supplied through electronic rectifiers. The output of the rectifiers is automatically controlled in accordance with the requirements of the driven machine or process. A simplified diagram of a circuit for constant-speed control obtained through armature control of the motor is shown in Fig. 71*G*. A circuit employing field control would be similar, with the location of the field and armature simply interchanged. When both field and armature control are employed, for wide speed range, the armature and field supply circuits are essentially duplicates of each other. The automatic control feature for holding constant speed would be applied to only one of the supply circuits.

In the circuit of Fig. 71*G*, the conversion element, or pickup, is the pilot generator, which is coupled to the d-c motor. The voltage of the pilot generator, which is proportional to the speed of the motor, is impressed upon the comparison circuit in such a manner as to oppose the reference voltage. The activation or correction circuit consists of an *RL* phase-shift grid-control circuit of the thyratrons. Variation of the phase shift is obtained by varying the reactance of the saturable-core reactor. The rectifier in the comparison circuit is for the purpose of blocking induced a-c voltages from the comparison circuit. The resistances R_g prevent excessive grid currents, and the capacitors C_g tend to absorb voltage surges in the grid circuits which would prevent satisfactory operation of the thyratrons.

The circuit of Fig. 71*G* functions in the following manner to hold the speed of the motor constant: The resistor R is adjusted to the proper value for the desired constant speed. If the speed of the motor rises above the value corresponding to the setting of R, the greater opposing voltage of the pilot generator will reduce the direct current through the center leg of the saturable reactor, and thereby shift the phase of the thyratron grid voltages in such a manner as to reduce the conduction period of the thyratrons. Thus the input to the motor is reduced, and the speed of

the motor is reduced until equilibrium conditions are reestablished. The equilibrium condition is the constant speed for which resistor R is set. In a similar manner, if the speed of the motor tends to drop below the constant speed, the circuit will function to increase the input to the motor armature and thereby restore equilibrium conditions. The circuit of Fig. 71*G* is simplified in order to bring out the fundamental principles. Actual circuits employed would be more complicated. Stable operation would require the addition of antihunt circuits and, in some cases, also filter

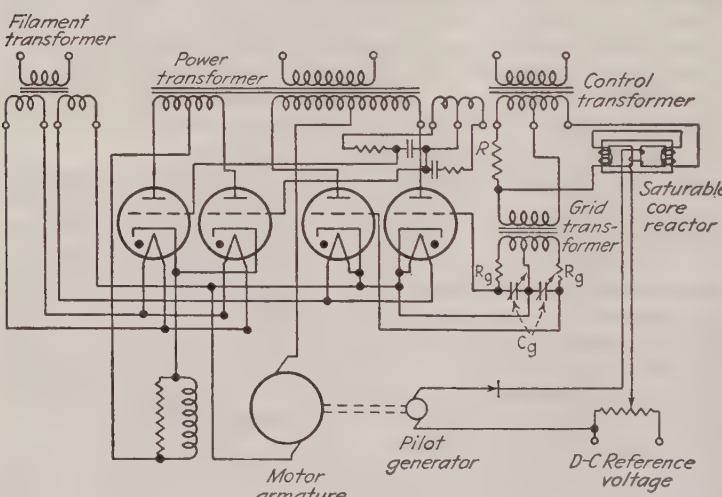


FIG. 71*G*.—Automatic-drive electronic speed control.

circuits to smooth out the ripples in the rectified current supplied to the motor. The power supply, generally, would be taken from a three-phase system, and a three-phase thyratron rectifier would be used instead of the single-phase full-wave rectifier shown.

140B. Automatic electrodynamic drive control is frequently called a **servo system.** In electrodynamic control of d-c motors, the input to the motor is automatically controlled in accordance with the requirements of the load by means of a control generator. Small motors may be directly supplied with power from the control generator. When the capacity of the control generator is not sufficient to supply the motor directly, the control generator energizes the field of a main generator and thus controls the input to the motor. Electrodynamic control circuits for constant-speed control of a d-c motor are shown in Figs. 71*H* and 71*I*. The circuit of Fig. 71*H* employs an amplidyne control generator and that of Fig. 71*I* a rototrol control generator. When a sufficient speed range can be obtained by field control, the control generator may control the input

to the field of the motor instead of the input to the armature, as is shown in the figures. In the circuits of both Fig. 71*H* and Fig. 71*I*, the conversion element, or pick up, is the pilot generator, which is coupled to the

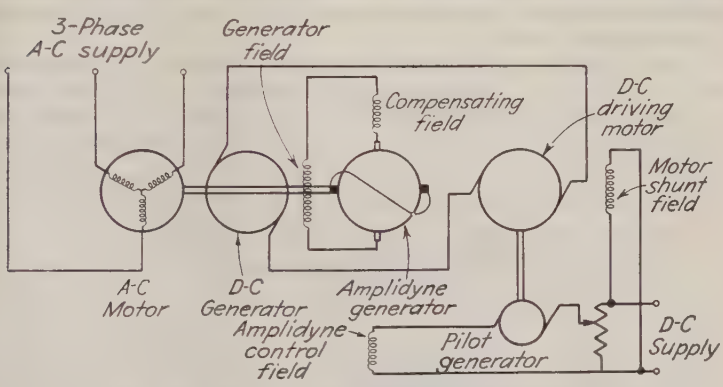


FIG. 71*H*.—Speed control using amplidyne generator.

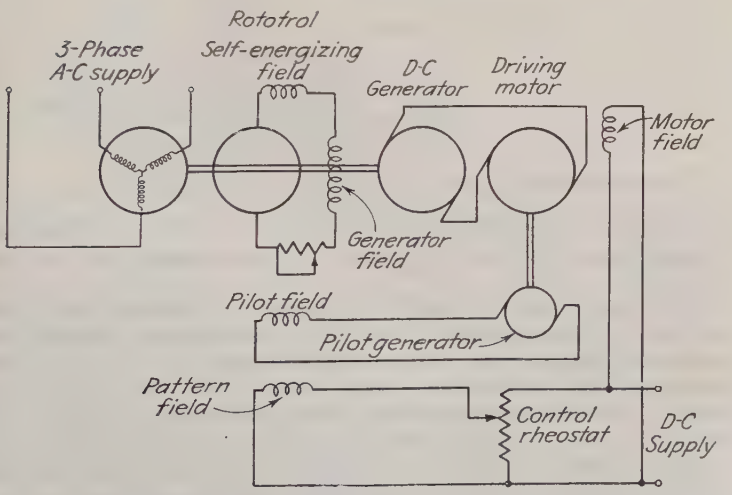


FIG. 71*I*.—Speed control using rototrol.

main d-c drive motor. In the circuit of Fig. 71*H*, the voltage of the pilot generator is impressed upon the comparison circuit in such a manner as to oppose the reference voltage. In the circuit of Fig. 71*I*, the voltage of the pilot generator energizes the pilot field of the rototrol. The comparison circuit of Fig. 71*I* consists of the combination of the pilot- and pattern-field circuits. In the circuits of both figures, the activation circuit is the armature circuit of the control generator. When the signal voltage from

the pilot generator is not sufficient to actuate the field circuit of the control generator directly, an electronic amplifier is inserted between the pickup circuit and the field of the control generator. In both the circuits shown in the figures, the circuit is adjusted for the desired speed by means of the adjusting rheostat.

In the amplidyne control circuit of Fig. 71*H*, if the speed of the motor rises above the value corresponding to the setting of the adjusting rheostat, the greater opposing voltage of the pilot generator weakens the field of the amplidyne. This will lower the voltage output of the amplidyne and thereby weaken the field of the main generator. The voltage output of the main generator is thus reduced. Therefore, the input and

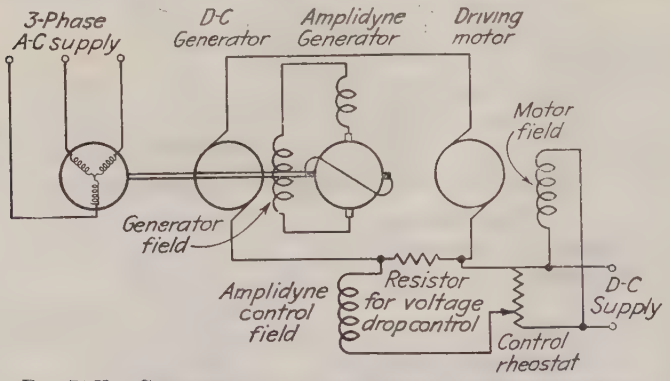


FIG. 71*K*.—Constant-current control using amplidyne generator.

consequently the speed of the motor are reduced until the speed has been brought back to the value determined by the setting of the adjusting rheostat.

In the rototrol circuit of Fig. 71*I*, if the speed of the motor rises above the value corresponding to the setting of the adjusting rheostat, the strength of the pilot field of the rototrol is increased. Since the pilot field opposes the constant pattern field, the field flux of the rototrol will be reduced. This will lower the voltage of the rototrol and thereby weaken the field of the main generator. The voltage output of the main generator is thus reduced. Therefore, the input and consequently the speed of the motor are reduced until the speed has been brought back to the value determined by the setting of the adjusting rheostat.

Circuits for constant-current control of a d-c motor by means of electrodynamic control systems are shown in Figs. 71*K* and 71*L*. The pickup element consists of a resistor in series with the motor armature circuit. Any deviation in the armature current will result in a proportionate change in voltage across this resistor. The voltage across the resistor activates the comparison circuit in the same manner discussed for the constant-speed controls.

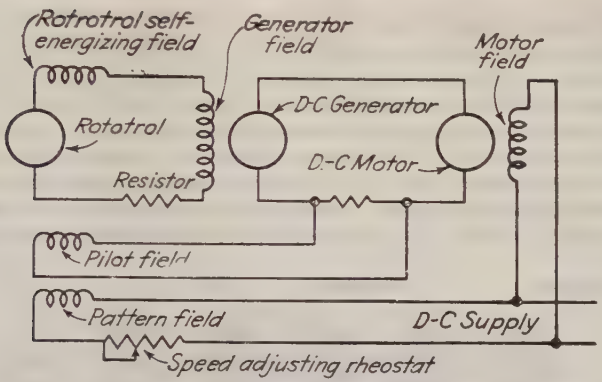


FIG. 71L.—Constant-current control using rototrol control generator.

140C. Position Control.—It is often desirable to have a control system that functions to control the position of a driven object or rotating machine. The position of a driven object may be indicated by a phototube scanning the driven object. The angular position of a rotating machine may be indicated by the error voltage of a synchro circuit (see Sec. **170A**). The phototube or synchro pickup and conversion element can actuate either an electronic or an electrodynamic control system so as to control the process or driven machine in accordance with the position desired.

141. Approximate Efficiencies of D-c Motors—Continuous Rated, 40°C. Rise

Hp.	Percentage efficiency			Hp.	Percentage efficiency		
	One-half load	Three-fourths load	Full load		One-half load	Three-fourths load	Full load
½	62.0	65.0	68.0	20	82.0	85.0	86.5
¾	65.0	70.0	72.0	25	83.0	86.0	87.0
1	70.0	73.0	75.0	30	84.0	87.0	88.0
1½	72.0	76.0	78.0	40	85.0	87.5	88.5
2	72.0	77.5	81.0	50	85.5	88.0	89.5
3	72.0	77.0	79.0	60	85.5	88.0	90.0
5	77.0	81.0	81.5	75	86.0	89.0	90.5
7½	79.0	82.0	83.5	100	86.0	89.0	90.5
10	81.0	83.0	85.0	125	86.0	89.0	90.5
15	81.5	84.5	86.0	150	87.0	90.0	91.0
				200	89.0	91.5	92.0

142. General Construction of Polyphase Induction Motors.—Polyphase induction motors have two windings, one on the stationary part of the machine or stator, and one mounted on the revolving part or rotor. The stator winding is embedded in slots in the inner surface of the frame of the machine and is similar to the armature winding of a revolving-field type of a-c generator. The rotor winding may be one of two types: squirrel cage or wound rotor. In the case of a **squirrel-cage** machine the rotor winding consists simply of copper or aluminum bars embedded in slots in the iron core of the rotor and connected together at each end by

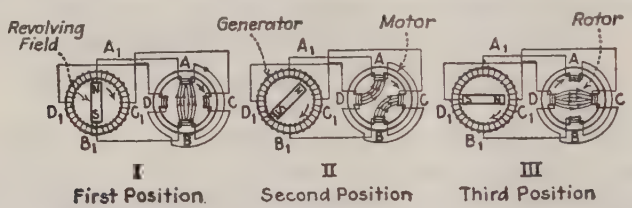


FIG. 72.—Illustrating the principle of the induction motor.

means of a copper or aluminum ring. The rotor winding thus forms a complete closed circuit in itself. The rotor winding of the **wound-rotor** machine is similar to the armature winding of a revolving-armature type of a-c generator. The free ends of the winding are brought out to slip rings. The rotor circuit is not closed until the slip rings are connected either directly together or through some resistances external to the machine.

143. Principle of Operation of the Induction Motor.—The induction motor differs from other types of motors in the fact that there is no electrical connection from the rotor winding to any source of electrical energy. The necessary voltage and current in the rotor circuit are produced by induction from the stator winding. The operation of the induction motor depends upon the production of a revolving magnetic field. The stator winding of a simple two-phase induction motor connected to a simple two-phase alternator is shown in Fig. 72.

Windings of the types shown in the illustration are not used in commercial machines, but the general theory involved is the same as with commercial windings. The revolving field (see illustration) of the generator, in turning in the direction shown by the arrow, generates a two-phase current, which is transmitted to the motor. The current, in conductors of one phase, magnetizes poles A and B, and that in the other phase the poles C and D The winding is so arranged that a current entering at A will produce a south pole at A and a north pole at B. At the instant shown at I, the motor poles A and B are magnetized while poles C and D are not, because it is a property of a two-phase circuit that, when the current in one of the phases is at a maximum value, the current

in the other phase is at a zero value. Hence, at this instant a magnetic field will be set up in the machine in a vertical direction, with a north pole at B and a south pole at A.

At another later instant, represented at II, the currents in both of the phases are equal and in the same direction. The motor poles will be magnetized as shown. The currents in changing from their values in I to their values in II have moved the magnetic field through an angle of 45 deg. toward the right. At the instant illustrated at III, because of the properties of two-phase currents there is no current in the phase of the conductors which are wound on poles A and B, but the current in the phase of the conductors which magnetize poles C and D is a maximum. Hence, the magnetic field produced in the machine at instant III is in a horizontal direction with a south pole at C and a north pole at D. The magnetic field has been moved around another 45 deg. Similar action occurs during successive instants, and the magnetic field is caused to rotate continually in the same direction within the motor frame so long as the two-phase current is applied to the stator terminals. Thus, when the stator winding of a polyphase motor is connected to a source of polyphase power, a revolving field is produced inside the machine.

If a closed electric circuit such as the rotor winding of an induction motor is inserted in the machine, the revolving magnetic field will cut across the conductors of this winding and in that way produce a voltage in them. This voltage acting upon the closed rotor circuit will send a current through the different conductors of the rotor winding. The rotor conductors then will be carrying a current and lying in a magnetic field. Such a condition will produce a force upon the conductors of the rotor winding tending to turn them in the same direction as that in which the magnetic field is revolving.

If the rotor winding was revolved at the same rate of speed as that at which the magnetic field revolves, there would be no relative motion between the field and the conductors of the rotor winding. Since there would be no relative motion, there would be no cutting of the magnetic field across the conductors, and therefore no voltage or current produced in the rotor winding. If there is no current in the rotor winding, there can be no torque produced, tending to keep the machine revolving. As the machine slows down, however, the magnetic field will revolve at a higher speed than the rotor, producing a relative motion between the magnetic field and the conductors of the rotor winding. This relative motion produces a cutting of the conductors by the flux, with the resultant voltage and current necessary to develop a turning effort upon the rotor. The operation of an induction motor depends upon a difference in speed between the revolving magnetic field and the actual speed of the machine or rotor. This difference in speed is called the slip of the motor. The rotor is said to slip a certain number of revolutions behind the revolving magnetic field. The greater the load on an induction motor, the more

the rotor must slip behind the revolving magnetic field in order to produce a greater cutting of the flux by the rotor conductors, with the resulting greater current in the rotor and greater turning effort to carry the greater load. Even at no load an induction motor cannot revolve as fast as the magnetic field revolves, since enough torque must be developed to overcome the friction and other losses in the motor.

144. Synchronous speed of an induction motor is the speed at which its magnetic field revolves. It depends upon the number of poles for which the stator is wound and the frequency of the supply voltage.

$$\text{Synchronous speed} = \frac{120f}{P} \qquad (4)$$

where f = frequency of supply; P = the number of poles per phase for which the stator is wound; and synchronous speed is in r.p.m.

145. The slip of an induction motor is the ratio of the difference between the rotating magnetic-field speed (r.p.m. or angular velocity) and the actual rotor speed to the rotating magnetic-field speed. The speed of the rotating magnetic field is equivalent to the synchronous speed of the machine (see table of synchronous speeds elsewhere in this section) which is determined by the frequency of the current and the number of poles of the machine (Sec. **144**). Then

$$\text{Slip in r.p.m.} = \text{synchronous speed} - \text{actual speed} \qquad (5)$$

$$\text{Per cent slip} = \frac{\text{synchronous speed} - \text{actual speed}}{\text{synchronous speed}} \times 100 \qquad (5a)$$

When there is no load on a motor the slip is very small, *i.e.*, the rotor speed is practically equal to the synchronous speed. Slip varies with the design of a motor and may vary from 4.0 to 8.5 per cent at full load in motors of from 1 to 75 hp. of ordinary design.

Example.—What is the slip at full load of a four-pole, 60-cycle induction motor which has a full-load speed of 1,700 r.p m.?

Solution.—From Table 97 or Sec. **144** the speed of the rotating field or the synchronous speed of a four-pole, 60-cycle motor is 1,800 r.p.m. Then, substituting in the above formula

$$\text{Per cent slip} = \frac{\text{synchronous speed} - \text{actual speed}}{\text{synchronous speed}} \times 100 = \frac{1{,}800 - 1{,}700}{1{,}800} \times 100 =$$

$$\frac{100}{1{,}800} \times 100 = 5.5 \text{ per cent}$$

Therefore the slip is 5.5 per cent. The voltage of the motor or whether it is single-phase, two-phase, or three-phase are not factors in the problem.

146. The Breakdown Torque of an Induction Motor.—Most induction motors will "breakdown" at some certain torque if they are overloaded. The "breakdown" limit—the maximum running torque that can be developed—is that point at which further increase in load will cause the motor speed to decrease rapidly and then to stop. This point is usually

at between two and four times the full-load rated torque, depending on the design and the capacity of the motor. In a few cases there is no breakdown torque, the maximum torque occurring at standstill. Under these conditions there will be no sudden decrease in the speed as the load is increased. The speed will gradually decrease as load is increased until standstill is reached.

147. General Operating Characteritics of Induction Motors.—The following rules, though somewhat approximate, are accurate enough for practical use under the normal range of operation of an induction motor from no load to 150 per cent of rated load.

The slip of an induction motor varies directly with the load. Doubling of the load will double the slip.

For any given load the slip varies directly with the resistance of the rotor circuit. If the resistance of the rotor circuit is doubled, the slip for the same load will be twice its original value.

For any load the slip varies inversely as the square of the voltage impressed on the stator winding. If the voltage is reduced to one-half of its normal value, the slip is increased to four times its normal value for any load.

The torque developed by an induction motor varies directly with the slip.

The torque developed at any particular slip varies inversely with the resistance of the rotor circuit.

The torque for any particular slip varies directly as the square of the voltage impressed on the stator.

The maximum torque is not affected by the resistance of the rotor circuit. A large value of resistance for the rotor circuit simply makes the maximum torque occur at a high slip.

The maximum torque varies directly with the square of the voltage impressed on the stator circuit.

148. Starting Characteristics of Induction Motors.—The starting torque varies directly with the square of the voltage impressed on the stator. If three-fourths of normal voltage is impressed at starting, the starting torque will be equal to only nine-sixteenths of the torque developed with normal voltage impressed at starting.

The value of the starting torque of an induction motor also depends upon the value of the resistance of the rotor circuit. As the resistance of the rotor circuit is increased, the starting torque is increased until the resistance of the rotor circuit is of just the right value to make the maximum torque occur at starting. If the resistance of the rotor circuit is still further increased, the starting torque will be decreased. Thus, there is a certain value of rotor resistance that will produce maximum starting torque, either a greater or smaller value of rotor resistance than this amount producing less starting torque (see Fig. 75).

The current taken at starting by an induction motor depends upon the

voltage impressed on the stator and the resistance of the rotor circuit. For a fixed rotor resistance the starting current varies directly with the impressed voltage. For a particular impressed voltage, increasing the resistance of the rotor circuit decreases the value of the starting current.

149. Characteristic Curves of the Induction Motor.—The curves of Fig. 73 are fairly typical of the average normal-torque, normal-starting-

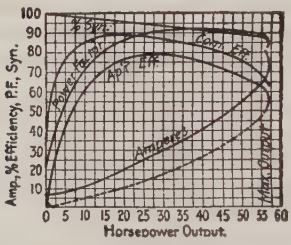


FIG. 73.—Typical performance graphs of a 20-hp., three-phase induction motor.

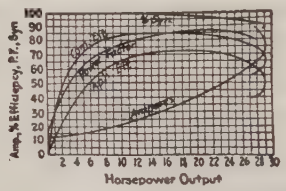


FIG. 74.—Performance graphs of the motor shown in Fig. 73, when running single-phase.

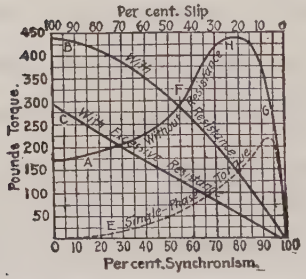


FIG. 75.—Torque graphs of a 30-hp. induction motor.

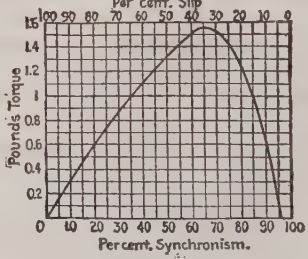


FIG. 76.—Torque graphs of a 1-hp., three-phase induction motor, running single-phase.

current, commercial induction motor. It will be noted that the normal rating of the motor is taken at such a point that both the power factor and the efficiency are the highest possible. The motor could be so designed that either the power factor or the efficiency, but not both, could be higher than shown at normal load, but the design of an induction motor is a compromise between the leading factors resulting in the best efficiency and power factor obtainable with suitable overload and starting characteristics.

The characteristics of a polyphase induction motor running single-phase are shown in Fig. 74. In Fig. 76 is shown the speed-torque characteristic of a polyphase induction motor running single-phase. It will be noted that the starting torque when operated single-phase is zero.

A polyphase induction motor will not start when connected to a single-phase supply. If it is once started, however, it will operate from a single-phase supply and carry approximately half rated load without overheating.

150. The torque curves of an induction motor with a wound rotor, from rest to synchronism, running both three-phase and single-phase with resistance and without resistance, are shown in Fig. 75. The curves are plotted with torque in pounds at 1 ft. radius. Curve *A* shows the torque from rest to synchronism without resistance in the rotor circuit. If resistance is inserted, curve *B* is obtained, and the starting torque is 440 lb. against 170 lb. without resistance. Curve *C* indicates the torque where too much resistance is used in the rotor. Curve *E* illustrates the torque for single phase, which is zero at starting. An induction motor starts as shown on curve *B* until it reaches the point *F*, when the resistance is cut out and the motor adjusts itself to its operating position at *G*. Thus, if the torque required of the motor for which the curve is shown is greater than 440 lb., shown at *H*, the motor will break down and come to rest. With the resistance in the rotor, a starting torque of 440 lb. is available, but this load cannot be brought up to normal speed. The motor can bring only the torque represented by the point *F*, in other words 290 lb., up to normal speed.

In Fig. 75 it will be noted that the torque of a three-phase motor rises to a maximum and then drops, reaching zero at synchronism. This means that an induction motor never runs at synchronous speed.

151. Speed Control of Induction Motors.—It is possible to control the speed of an induction motor by any one of the following methods:

1. Changing impressed voltage.
2. Changing number of poles for which the machine is wound.
3. Changing the frequency of the supply.
4. Changing the resistance of the rotor circuit.
5. Introducing a foreign voltage into the secondary circuit.
6. Operating two or more motors connected in cascade.

152. Reducing the impressed voltage will increase the slip of an induction motor proportionally to the square of the voltage. At the same time, however, the breakdown torque of the motor is also reduced as the square of the voltage, so that there is danger of the motor stalling under load. For this reason, changing the impressed voltage is employed for the speed control of induction motors only in emergencies or other special cases.

153. Speed Control of Induction Motors by Changing the Number of Poles.—The actual speed of an induction motor depends upon the speed of the revolving magnetic field produced by the stator winding (synchronous speed). The synchronous speed of an induction motor is inversely proportional to the number of poles for which the stator winding is wound. Thus, on a 60-cycle circuit a two-pole induction motor has a

synchronous speed of 3,600 r.p.m.; a four-pole motor, 1,800 r.p.m.; an eight-pole motor, 900 r.p.m.; etc. It is, therefore, possible to alter the speed of an induction motor by changing the number of its poles.

This can be accomplished by using two or more separate primary windings, each having a different number of poles, or by using a single winding which can be connected so as to form different numbers of poles. This method is, of course, not applicable to the ordinary type of induction motor but requires a motor with a number of leads brought out from the primary winding (see Multispeed motors, Sec. **165**). Gradual speed control cannot be obtained by this method. Only a certain number of definite speeds, four at the most, can be obtained.

154. Speed Control of a Polyphase Motor by Adjusting the Frequency of the Primary Current.—Since the synchronous speed of an induction

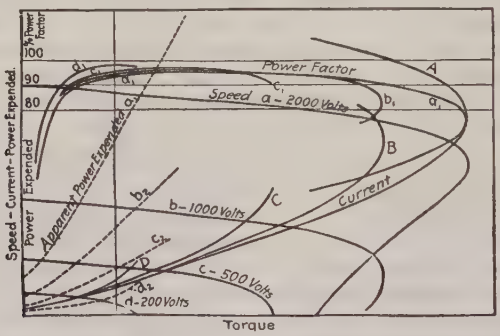


FIG. 77.—Performance graphs of a polyphase induction motor with different applied frequencies and different applied electromotive forces.

motor is equal to the alternations per minute of the supply circuit divided by the number of poles in each phase circuit, a change in speed can be effected by changing the frequency of the supply circuit.

Figure 77 shows the speed-torque and other curves of a 60-cycle motor when operated at 60, 30, 15, and 6 cycles, or at 100, 50, 25, and 10 per cent of the normal frequency. The speed-torque curves corresponding to the above frequencies are *a*, *b*, *c*, and *d*. The current curves are *A*, *B*, *C*, and *D*. This figure shows that for the rated torque *T* the current is practically constant for all speeds, but the e.m.f. varies with the frequency. Consequently, the apparent power supplied, represented by the product of the current by e.m.f., varies with the speed of the motor and is practically proportionate to the power developed.

In a few cases, where only one motor is operated, the generator speed can be varied. If the generator is driven by a water wheel, its speed can be varied over a wide range, and the motor speed will also vary. If the generator field is held at practically constant strength, then the motor

speed can be varied from zero to a maximum at constant torque with a practically constant current.

Controlling the speed of an induction motor by changing the frequency of the supply requires a separate generator for each motor. This method is, therefore, not feasible for ordinary speed-control applications. It is sometimes employed in special cases for the control of large units requiring very fine speed control.

155. Speed Control of Induction Motors by Adjusting the Resistance of the Secondary Circuit.—Inserting resistance in series with the rotor of an induction motor will decrease the speed of the motor. The amount of decrease in speed produced will depend upon the load on the motor. It is not possible to produce much change in speed by this method at light loads. This method of speed control is of course only applicable to wound-rotor motors. Speed control by adjusting the resistance of the rotor circuit has two drawbacks. After the speed has been adjusted for any load, the speed does not remain constant with change in load. With external resistance in series with the rotor, the motor has a varying speed characteristic. Considerable power is wasted in the external resistance required for changing the speed. The amount of power wasted depends upon the value of the external resistance. The efficiency of the motor is thus decreased approximately proportionally to the reduction in speed.

Speed control by means of adjustable secondary resistance is, however, very useful where constant speeds are not essential, for example, in operating cranes, hoists, elevators, and dredges and also for service in which the torque remains constant at each speed, as in driving fans, blowers, and centrifugal pumps. In service where reduced speeds are required only occasionally and where speed variation is not objectionable this method of control can also be used to good advantage. On account of energy loss in the resistors, the efficiency is reduced when operating at reduced speeds, this reduction being greatest at the slowest speeds. The circuits are essentially the same as for starting by varying resistance in the rotor circuit, as shown in Fig. 147*A*. The rotor usually has a Y-connected winding to which is connected, in series in each phase, an external resistance (Fig. 147*A*). By moving the adjustable arm, the amount of resistance in series in each phase can be varied from a maximum to zero and the speed varied gradually from the highest speed to the lowest.

156. Speed Control of Induction Motors by Introduction of a Foreign Voltage into the Secondary Circuit.—If a foreign voltage is introduced into the secondary circuit of an induction motor, it will alter the speed of the motor. If this foreign voltage acts in a direction opposite to that of the voltage induced in the secondary circuit, the speed of the motor will be reduced. If the foreign voltage acts in the same direction as the voltage induced in the secondary circuit, the speed of the motor will be increased. With this method of speed control it is possible to obtain speeds both above and below the synchronous speed of the motor. Speed

control by the introduction of a foreign voltage into the secondary circuit has two advantages. No power is wasted in resistance, and the speed is practically constant for all loads with the same value of foreign voltage introduced.

The brush-shifting and polyspeed types of polyphase induction motors, as explained in Sec. **169,** employ the foreign-voltage method of speed control. Where the operating characteristics of these motors are applicable, these motors provide a very efficient means of obtaining adjustable speed for a-c installations.

An electronic method of foreign-voltage speed control has been employed and is feasible for medium-sized and small motors. The dia-

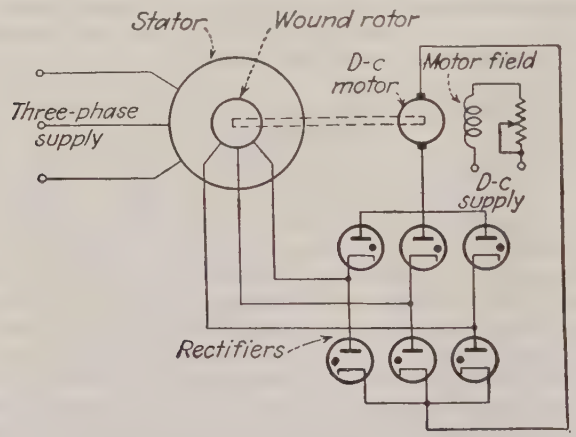


Fig. 77*A*.—Control of wound-rotor induction motor using electronic means.

gram of the circuit for such a method is shown in Fig. 77*A*. The armature of a d-c motor is connected through a three-phase full-wave ignitron or thyratron rectifier to the rotor slip rings of the induction motor. This connection introduces the counter-e.m.f. of the d-c motor into the rotor circuit of the induction motor. The value of the counter-e.m.f. of the d-c motor is adjusted by adjustment of the field rheostat of the d-c motor. The speed of the induction motor is, therefore, controlled through adjustment of the field rheostat of the d-c motor. The d-c motor may be mechanically coupled to the induction motor so that it helps to drive the load, or the d-c motor may drive an a-c generator so that the greater portion of the power taken by the d-c motor is returned to the a-c supply system.

There are other methods of obtaining speed control by the foreign-voltage method, but all of them require the use of additional revolving machines besides the motor itself. Their use is not feasible for ordinary applications. They are employed in special cases for the speed control of large motors.

157. Speed control of polyphase motors by operating two or more motors connected in cascade offers, under some conditions of service, the most convenient and economical method of speed variation. In this arrangement all the rotors are mounted on one shaft, or the several shafts are rigidly connected. The primary of the first motor is connected to the line; its secondary, which must be of the phase-wound, slip-ring type, is connected to the primary of the second motor; and so on. The secondary of the last motor can be of either the squirrel-cage or the phase-wound type. In practice more than two motors are rarely used. The arrangement is shown in Fig. 78.

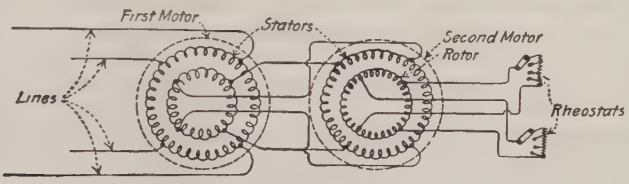


FIG. 78.—Two polyphase motors connected in cascade.

Speed changes are obtained by varying the connections of the motors, the following combinations being possible with two motors: each motor can be operated separately at its normal speed with its primary connected to the line, the other motor running idle; the motors can be connected in cascade so that the rotors tend to start in the same direction (direct concatenation); or the motors can be connected so that the rotors tend to start in opposite directions (differential concatenation). If the first motor has 12 poles and the second 4, the following synchronous speeds can be obtained on a 25-cycle circuit:

(1) Motor II (four poles) running single, 750 r.p.m.; (2) motors in differential concatenation (equivalent of eight poles), 375 r.p.m.; (3) motor I (12 poles) running single, 250 r.p.m.; (4) motors in direct concatenation (equivalent of 16 poles), 187.5 r.p.m. By the use of adjustable resistance in the secondary circuits, changes from one speed to the next can be made with uniform gradations.

A great number of speed combinations are possible by the use of this method; the control is simple and safe, as few leads are required and main circuits are not opened for most of the speeds. The rotors can be made with smaller diameters than is possible with other multispeed motors; hence the flywheel effect is reduced to a minimum. In general, a cascade set is applicable where speed changes must be frequently made with high horsepower output and primary voltage, and where the speed ratios are other than 1:2.

158. Application of the Methods of Speed Control of Induction Motors. From the discussion in the preceding sections it is apparent that the ordinary squirrel-cage induction motor is not suitable for common adjust-

able-speed application. When a few definite speeds will be satisfactory, the multispeed motor may be employed. In special cases, squirrel-cage motors which have their speed controlled by a change in the frequency of the supply may be advisable. Therefore, when speed control is required on polyphase a-c systems, the wound-rotor motor with variable external resistance in the rotor circuit, the brush-shifting type, or the polyspeed type must be employed, except for special applications.

159. The normal-torque, normal-starting-current motor is the old standard type of squirrel-cage induction motor. It is a constant-speed machine with a slip of from 2 to 5 per cent at full load. It is not adapted for speed-control service. The starting torques with rated voltage applied are at least as great as the following percentages of full-load torque:

Motor poles	Percentage of full-load torque	Motor poles	Percentage of full-load torque
2	150	10	120
4	150	12	115
6	135	14	110
8	125	16	105

The blocked-rotor starting currents with rated voltage applied vary from 500 to 1,000 per cent of full-load current, the smaller values being for motors with the larger number of poles.

The full-voltage starting currents of motors of 5 hp. and smaller will be within the limitations of most power companies, so they are generally started directly across the line. Motors of larger size than 5 hp. will have full-voltage starting currents that will not be within the limitations of many power companies and in the majority of cases are started with reduced voltage. This type of squirrel-cage motor has better all-round performance than any of the other types, having slightly better efficiency, regulation, breakdown torque, and power-factor characteristics. For normal-torque, squirrel-cage, induction-motor applications, the normal-torque, normal-starting-current type of motor should always be used when it is permissible to start it directly across the line. Whenever reduced voltage starting is required regardless of the type of induction motor employed, the normal-torque, normal-starting-current type should be used whenever it will produce sufficient starting torque under the required limitations of starting current.

The breakdown torques are from 200 to 250 per cent of full-load torque.

160. The normal-torque, low-starting-current, squirrel-cage motor is so designed that its rotor has a high reactance and resistance at start but nearly normal reactance and resistance under running conditions. This

enables this type of motor to produce approximately the same starting torque for a given voltage as the normal-torque, normal-starting-current motor but with a much smaller value of starting current.

The running performance will be very nearly but not quite so good as that of the normal-torque, normal-starting-current type, the efficiency, power factor, and breakdown torque being slightly less and the speed regulation slightly larger. The breakdown torques vary from 200 to 225 per cent of full-load torque. The blocked-rotor starting current with rated voltage applied will be approximately 500 to 550 per cent of the full-load currents. The full-voltage starting currents of motors of 30 hp. and smaller will be within the limitations of most power companies, so they are generally started directly across the line. Motors of larger size than 30 hp. will have full-voltage starting currents that will not be within the limitations of many power companies and therefore frequently must be started with reduced voltage.

161. Low-torque low-starting-current, squirrel-cage motors are made by some manufacturers in sizes 40 hp. and larger. Above 30 hp. the full-voltage starting current of the normal-torque, low-starting-current type of motor exceeds the limitations of many power companies. By designing a motor for a lower starting torque, however, it is possible to build motors of larger size that will meet these starting-current limitations. The full-voltage starting torque of these motors varies from 50 to 100 per cent of full-load torque. The full-voltage starting currents will vary from 350 to 550 per cent of the full-load current. The breakdown torques will vary from 125 to 175 per cent of full-load torque. The full-voltage starting currents of these motors will be within the limitations of most power companies. They would not be used if reduced-voltage starting were required. This motor should be used only for drives which are started with light loads, such as motor generator sets, fans, and centrifugal pumps.

162. High-torque low-starting-current, squirrel-cage induction motors are usually constructed with two squirrel-cage windings on the rotor, located one above the other in the rotor slots. During the starting period most of the current is carried by the top winding, which has a high resistance. This enables the motor to produce a larger starting torque with about the same value of starting current as the normal-torque, low-starting-current type of motor. After the motor has come up to speed, the two windings are equally effective in carrying the rotor current, and its operating characteristics are similar to those of the normal-torque, low-starting-current type of motor.

The blocked-rotor starting currents with rated voltage applied will be approximately 500 to 550 per cent of the full-load currents. The full-voltage starting current of motors of 30 hp. and smaller will be within the limitations of most power companies, so that they are generally started directly across the line. Motors of larger size than 30 hp. will have full-voltage starting currents that will not be within the limitations of many

power companies and therefore frequently must be started with reduced voltage. The starting torques with rated voltage impressed vary from 200 to 275 per cent of full-load torque. The breakdown torques vary from 200 to 250 per cent of full-load torque.

163. The high-resistance-rotor type of squirrel-cage motor, owing to the high resistance of its rotor winding, produces a high starting torque with a low value of starting current.

They are made in two general types, which may be classified as medium slip and high slip. The medium-slip motors have full-load slips from 7 to 11 per cent while the high-slip machines have full-load slips from 12 to 17 per cent. The medium-slip motors are suitable for driving punch presses, shears, bulldozers, and other heavy-inertia machinery which operates under heavy, fluctuating-load conditions and which is either provided with flywheels or has flywheel effect. These motors have full-voltage starting torques of from 300 to 400 per cent of full-load torque and full-voltage starting currents of from 400 to 800 per cent of full-load current. The maximum torque of the motor occurs at standstill, so that there is no noticeable breakdown torque. The full-voltage starting currents are within the limitations of most power companies. Reduced-voltage starting would not as a rule be satisfactory, owing to the nature of their application.

The high-slip motors are designed for meeting the requirements of elevator drive and small cranes and hoists. These motors have full-voltage starting torques of from 225 to 250 per cent of full-load torque and full-voltage starting currents of from 300 to 500 per cent of full-load current. Their full-voltage starting currents will meet the limitations of practically all power companies. Like the medium-slip motors they have no breakdown torque. Owing to the nature of their application, reduced-voltage starting would not be satisfactory.

164. Automatic-start induction motors are so arranged that they start with a high-resistance rotor and, after coming up to speed, are automatically changed to have a low-resistance rotor. At start approximately one-third of the rotor copper is in service.

They are made in two types. In one type the machine is of generally normal contruction but with two rotor windings, one of high resistance and the other of low resistance. At standstill the low-resistance rotor winding is open-circuited so that only the high-resistance winding is in service. As the motor speeds up, a centrifugal device short-circuits the low-resistance winding so that both windings are in service.

In the other type of motor the primary winding is located on the rotor. There are two secondary windings located on the stator, one of high resistance and the other of low resistance. The functioning of the two windings is controlled by magnetic switches so that there is no centrifugal device. The low-resistance winding is of the wound type, and the high-resistance one is a squirrel-cage winding. In starting, a magnetic contactor connects the primary to the line, with the low-resistance winding

open-circuited. After a certain lapse of time, a second contactor closes, short-circuiting the low resistance winding.

These automatic-start motors are started on full voltage and have starting torques from 225 to 250 per cent of full-load torque, with starting currents from 350 to 375 per cent of full-load current. Their breakdown torques vary from 200 to 250 per cent of full-load torque and they have pull-in torques of from 150 to 200 per cent of full-load torque. They are suitable for high-starting-torque duty where the starting periods are not too frequent or of too long duration, such as compressors and air-conditioning-equipment service. They can be used in many places where the power company will not allow the starting currents drawn by the high-torque, low-starting-current motors when thrown directly across the line.

165. Multispeed induction motors are squirrel-cage induction motors constructed so that the number of poles for which the stator is wound may be altered. Since the speed of an induction motor depends upon the number of poles for which the stator is wound, changing the number of poles will alter the speed of the motor. The change in the number of poles is produced either by means of entirely separate windings or by changing the interconnections of the different parts of a single winding. In either case the necessary leads are brought out from the stator winding to a drum controller through which the necessary change in connections is made. A gradual speed control is not possible with the multispeed motor. Motors of this type which may be operated at two, three, or four different speeds may be obtained. Four different speeds is the maximum number for which it is feasible to construct multispeed induction motors. To design and construct a machine for more than four speeds would require too many complications in the wiring.

Multispeed induction motors have a practically constant speed from no load to full load for each one of their rated speed connections.

Multispeed induction motors are available in all the following types:

1. Normal torque, normal starting current.
2. Normal torque, low starting current.
3. High torque, low starting current.
4. Low torque, low starting current.
5. High resistance medium or high slip.

Multispeed induction motors may be designed and rated for constant-torque service, constant-horsepower service, or varying-torque, varying-horsepower service. The allowable rating of the constant-torque motors varies directly with the speed. The constant-horsepower motors have the same rated horsepower for all speeds. With the varying-torque, varying-horsepower motors the full-load rated torque varies directly with the speed. The horsepower rating of these machines, therefore, varies as the square of the speed.

166. Wound-rotor induction motors, when operated with no external resistance in the rotor circuit and with the slip rings short-circuited, have

operating characteristics similar to those of the normal-torque, normal-starting-current, squirrel-cage machine. By inserting external resistance in the rotor circuit, the speed of the motor may be controlled. With load on the motor the speed may be controlled over a wide range. At no load and with light loads on the motor, it is possible to obtain only slight changes in the speed. When the speed is adjusted for any particular load, the speed does not stay constant as the load varies, but decreases considerably as the load increases. The amount that the speed drops off from no load to full load depends upon the amount of external resistance in the rotor circuit; the greater the resistance the greater the speed change. The characteristics of the wound-rotor motor operating with external resistance in the rotor circuit are similar to those for a d-c motor with armature control. Considerable energy is lost in the external resistance, the efficiency of the motor being reduced approximately in proportion to the reduction in speed produced. Wound-rotor motors are started by throwing the stator directly across the line with external resistance in the rotor circuit. The value of the starting torque developed and the corresponding starting current depends upon the amount of external resistance in the rotor circuit (see Secs. **148** and **150**). The breakdown torque of a wound-rotor motor is from 200 to 275 per cent of full-load torque. With the proper amount of external resistance in the rotor to produce maximum torque at standstill the starting current will be from 250 to 300 per cent of the full-load current. The maximum value of the starting torque will be from 200 to 275 per cent of full-load torque.

Wound-rotor motors with speed control are constant-torque machines, the horsepower decreasing in proportion to the decrease in speed.

167. Average Efficiencies and Power Factors for Polyphase Wound-rotor Induction Motors (with Rotor Short-circuited)

Hp.	Efficiency			Power factor		
	One-half load	Three-fourths load	Full load	One-half load	Three-fourths load	Full load
2	71.0	75.0	75.5	40	52	60
3	75.0	78.0	79.0	50	68	70
5	78.0	80.0	80.5	60	75	77
7½	78.5	81.0	81.5	65	75	78
10	80.0	82.0	82.5	65	75	79
15	80.0	82.0	82.5	65	75	79
20	84.0	85.5	86.0	70	76.5	81
25	86.0	88.0	88.0	70	77	81
30	86.0	88.0	88.0	72	78	82
40	86.0	88.0	88.0	72	78	82
50	86.0	88.0	88.0	78	84	86
60	86.5	88.5	88.5	79	85	88
75	88.0	88.0	88.8	82	87	89

168. Average Efficiencies and Power Factors for Polyphase Squirrel-cage Induction Motors

Hp.	Efficiency			Power factor		
	One-half load	Three-fourths load	Full load	One-half load	Three-fourths load	Full load
½	60.0	67.0	69.0	45	56	65
¾	64.0	68.0	69.0	48	58	65
1	75.0	77.0	76.0	57	69	76
1½	75.0	77.0	78.0	64	76	81
2	77.0	80.0	81.0	68	79	84
3	80.0	82.0	81.0	70	80	84
5	80.0	82.0	82.0	76	83	86
7½	83.0	85.0	85.0	77	84	87
10	83.0	85.0	85.0	77	86	88
15	84.0	86.0	88.0	81	85	87
20	87.0	88.0	87.0	82	86	87
25	87.0	88.0	87.5	82	86	87
30	87.5	88.5	88.0	83	86.5	87
40	87.5	89.0	89.5	84	87	88
50	87.5	89.0	89.5	84	87	88
60	88.0	89.5	89.0	84	87	88
75	88.5	89.5	89.5	84	87	88
100	89.0	90.0	90.5	84	88	88
125	90.0	90.5	91.0	84	88	89
150	90.0	91.5	92.0	84	88	89
200	90.0	91.5	92.0	85	89	90
250	91.0	92.5	93.0	84	89	90
300	92.0	93.5	94.0	84	89	90

169. In the commutator brush-shifting type of polyphase induction motor the relative location of the two windings is reversed from that of the ordinary induction motor. The primary winding, the winding that is connected to the supply, is located on the rotor. The secondary winding is placed in the stator slots. In addition to the primary winding the rotor carries a second winding which is connected to a commutator in the same manner as in a d-c motor. The two ends of each phase of the secondary winding (the stationary winding) are connected to two brushes bearing upon the commutator. The arrangement and connection of the windings are indicated in Fig. 79. The position of the two brushes of each phase may be shifted by means of a handwheel. When the handwheel is adjusted so that the brushes of each phase are on the same commutator segment, the secondary winding is short-circuited, and the motor operates like a squirrel-cage machine. As the brushes are moved apart a section of the adjusting winding is placed in series with the secondary winding. This impresses upon the secondary an additional voltage to the

one induced in it by the revolving magnetic field. If the brushes are moved in one direction, the voltage impressed by the adjusting winding will oppose the normal induced voltage. Such a shift of the brushes will, therefore, reduce the speed of the machine. A shifting of the brushes in the opposite direction causes the voltage from the adjusting winding to aid the normal induced voltage in the secondary and thus increases the speed of the motor. These machines are designed to give a speed range of 3:1. The highest speed is approximately 40 per cent above synchronous speed, and the lowest speed is approximately 60 per cent below synchronous speed. The decrease in speed from no load to full load is from 5 to 10 per cent at the high speeds, and from 15 to 25 per cent at the low speeds. Very low creeping speeds can be obtained by inserting resistance in the rotor circuit.

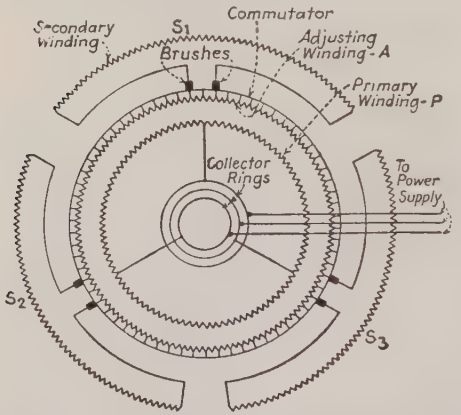


FIG. 79.—Diagram of commutator type of polyphase induction motor. (*General Electric Co.*)

These brush-shifting motors are rated on a constant-torque basis so that the horsepower rating decreases with the speed. The breakdown torque at low speeds is from 140 to 250 per cent of full-load torque. The breakdown torque increases somewhat with the speed so that at the high speed it is from 300 to 400 per cent of normal torque.

These motors are started by connecting the primary directly to the line with the brushes in the low-speed position. In this way they will develop a starting torque of from 140 to 150 per cent of full-load torque with a starting current of from 125 to 175 per cent of full-load current for the maximum horsepower rating. In some special cases, resistance is connected in series with the secondary for starting.

170. The polyspeed induction motor (Fig. 80) has a stator winding similar to that of an ordinary three-phase induction motor. This winding is connected through a switch directly to the power supply and requires no adjustment. The rotor has a single winding connected to a commutator similar to a d-c armature winding. The commutator is fitted with three sets of brushes per pair of poles. The brushes are connected to the secondary terminals of an open delta-connected induction regulator, which has its primary connected to the three-phase power

supply (see Fig. 81). When the motor is operating, the voltage induced in the rotor winding between sets of brushes per pole will be an a-c voltage of power-supply frequency. Speed is controlled by the method of introducing a foreign voltage into the secondary or rotor circuit. This foreign voltage is obtained from the secondary of the induction regulator. By adjusting the handwheel on top of the regulator the position of the secondary windings of the regulator can be adjusted with respect to the regulator primary coils. By this means the secondary voltage of the

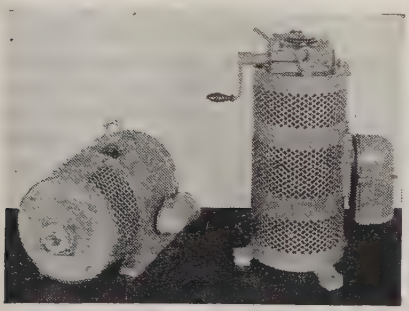


FIG. 80.—Polyspeed induction motor. (*Crooker-Wheeler Electric Manufacturing Co.*)

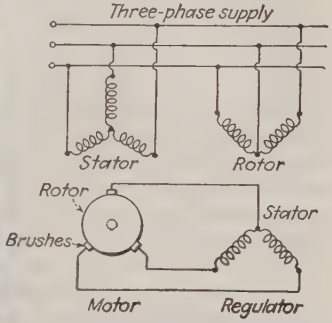


FIG. 81.—Diagram for polyspeed induction motor.

regulator can be adjusted from zero to maximum and made either to buck or aid the voltage induced in the rotor of the motor. Thus, any speed from zero to 150 per cent of synchronous speed can be obtained without rheostatic losses. There are some losses in the windings of the regulator so that the efficiency is somewhat less than for the ordinary induction motor. Although the speed can be reduced to zero, the motor cannot be operated continuously at speeds below 50 per cent of synchronous speed unless some external source of cooling is provided. The decrease in speed from no load to full load is approximately 10 per cent (180 r.p.m.) at the high speed and approximately 40 per cent (400 r.p.m.) at the low speed.

These polyspeed motors are rated on a constant-torque basis. The horsepower is therefore directly proportional to the speed. The rated horsepower as given by the manufacturers is for the highest speed. These motors may be started in all cases by connecting the stator directly across the supply with the regulator set in the minimum-speed position. The voltage from the regulator will then be opposing the voltage induced in the rotor, and the starting current drawn from the line will be low. If there is considerable load on the motor, it may not start when thrown on the line in this manner. The speed regulator should then be moved slowly toward the higher speed positions until sufficient

torque is developed to start the motor. The rate at which the motor accelerates and the current drawn from the line during the starting period depend upon the rapidity with which the speed regulator is moved over toward the higher speed positions. A starting torque equal to full-load torque will be developed with a little more than full-load current drawn from the line. A maximum starting torque of from 300 to 400 per cent of full load can be developed. The setting of the brushes will affect the power factor and efficiency. Motors for nonreversing service should have their brushes set in the position which gives maximum torque per ampere of rotor current. With this setting the power factor at the higher speeds should be slightly better than for the ordinary induction motor.

The motor can be reversed by interchanging any two of the line leads without changing the interconnection between the regulator and motor. The brush position which gives the best motor performance is not the same for both directions of rotation. Motors for reversing services should have their brushes set in a compromise position which will give substantially the same performance for either direction of rotation.

The breakdown torque of these motors is from 400 to 450 per cent of full-load rated torque for the high-speed adjustment. As the bucking voltage in the secondary is increased, the breakdown torque will decrease. With sufficient increase in the bucking voltage the maximum torque will occur at standstill.

170A. Synchros are special a-c motors employed for:

1. Remote indication of position, such as indicating the position of generator rheostats, water-wheel governors, water-reservoir levels, gates or valves, and turntables.

2. Remote signaling systems, such as signaling from switchboard to generator room, steel-mill furnace to blower room, and marine signals between engine room and bridge.

3. Automatic or remote position control, such as system frequency, synchronizing of incoming generators, water-wheel governors, gates or valves, color screens on lights in theaters, and motor drives (see Sec. **140C**).

4. Operation of two machines so as to maintain a definite time-position relation or a definite speed relation, such as lift bridges, hoists, kiln drives, elevators, unit printing presses, and conveyors.

Synchros are known by various trade names such as Selsyn, Synchrotie, Autosyn, and Telegon. Units are available in single-phase and three-phase types. The polyphase units conform in appearance and general characteristics to a three-phase wound-rotor induction motor. The single-phase units have a three-phase wound secondary and a single-phase primary. Some single-phase units are constructed with the primary located on the stationary member of the machine and others with the primary on the movable member. Depending upon the torque developed by the machine, synchros are classified as indicating synchros or power synchros. Power synchros are always of three-phase construc-

tion. Most of the indicating synchros are constructed single-phase. The indicating synchros are manufactured in a general-purpose type and a high-accuracy type. The general-purpose type will indicate angular position within an accuracy of plus or minus 5 deg. and the high-accuracy type provides an accuracy of indication within plus or minus 1 deg.

A synchro system requires the use of at least two synchro machines. The connections for two single-phase units are shown in Fig. 81*A* and those for two three-phase units in Fig. 81*B*. With both the single-phase and the polyphase units, if the rotors of the two machines are in corresponding positions, the voltages of the two secondaries at each instant of time will be equal in magnitude and opposite in direction. Therefore, no current will flow in the rotor circuits, no torque will be developed in either machine, and the machines will be in equilibrium. When the two rotors are not in corresponding positions, the voltages of the two secondaries will not neutralize each other, and a current will be produced in the two secondaries. This current will produce torque in the machines, which will act upon the rotors, tending to move them into corresponding positions.

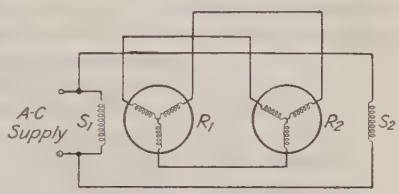


FIG. 81*A*.—Circuit for two single-phase synchros.

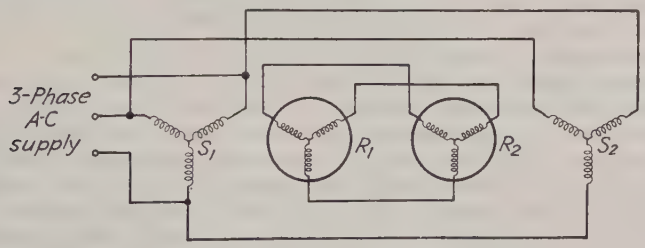


FIG. 81*B*.—Circuit for two three-phase synchros.

In signaling or indicating applications, the synchro located at the sending end is called the transmitter, and the synchro at the receiving end is called the receiver. If desired, a number of receivers may be connected in parallel to a single transmitter. The torque exerted upon each receiver will be reduced from that available when only one receiver is used. The torque can be calculated from the following formula:

$$T_r = T_1 \times \frac{2}{N+1} \qquad (5b)$$

where T_r is the torque available at each receiver, T_1 is the torque available if only one receiver is used, and N is the number of receivers.

When it is desired to have the position taken by the receiver differ

from that of the transmitter, a three-phase synchro is introduced between the transmitter and the receiver. This intermediate synchro is called a differential synchro. With such a system, the receiver will take up a position that will be either the sum or the difference of the angles applied to the transmitter and the differential. Conversely, if two synchros are connected through a differential synchro and each is turned through an angle, the differential synchro will indicate the difference between the two angles.

The fundamental synchro circuit generally used for control purposes is shown in Fig. 81*C*. When the positions of the rotors coincide, a maximum voltage will be induced in stator S_2. When the rotors are

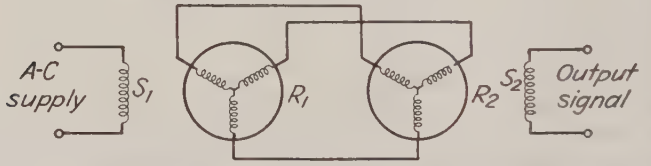


FIG. 81*C*.—Fundamental synchro control circuit for production of an error voltage.

displaced 90 electrical degrees from each other, no resultant voltage will be produced between the terminals of S_2. This is true, since the axis of the winding S_2 will be located 90 electrical degrees from the axis of the field produced in machine 2. The system is adjusted so that, when the desired condition exists, the rotors will be 90 electrical degrees displaced from each other. This is the equilibrium position. The circuit therefore functions to produce an error voltage in the stator of machine 2 whenever there is a displacement of the shafts from the equilibrium position. The relative polarity of the error voltage depends upon the direction of the displacement. The error voltage can be employed to instigate the functioning of other devices, which will operate to correct the condition causing the displacement. These correction devices will function until the synchros are brought into the equilibrium position, when absence of voltage in S_2 will stop their functioning. Refer to Sec. **140C** for application of synchros in position drive control.

171. Synchronous Motors.—The general construction of a synchronous motor is the same as that of synchronous a-c generators with the addition of an auxiliary winding similar to either the squirrel-cage or wound-rotor winding of an induction motor embedded in the pole faces. The purpose of the auxiliary winding is to produce starting torque so that the motor will be self-starting. A synchronous motor will not develop starting torque through synchronous-motor action. A synchronous motor is started without d-c field excitation by induction-motor action through its auxiliary winding. As the motor comes up to speed and d-c excitation voltage is applied to its field winding, a pull-in torque is

developed, tending to pull the motor into step. If the inertia of the load is not too great, this pull-in torque will accelerate the motor to synchronous speed, and it will continue to operate as a synchronous motor. As long as the motor runs at synchronous speed, the auxiliary winding will be inactive, since there will be no voltage produced in the auxiliary winding under this condition. If the motor should instantaneously tend to run at a speed slightly greater or less than synchronous, a voltage is produced in the auxiliary winding, producing a flow of current. This current will produce a torque which will act to bring the motor back to synchronous speed. The auxiliary winding, therefore, in addition to providing a means of making the motor self-starting provides a dampening effect tending to eliminate instantaneous fluctuations of the speed.

A synchronous motor has two very important characteristics. It operates at constant speed, and its power factor is under the control of the operator. If the average speed of a synchronous motor deviates from synchronism, the motor pulls out of step and ceases to function as a synchronous motor. Unlike an induction motor the power factor is not a fixed value dependent upon the design and load. The power factor is dependent upon the value of the d-c field current and can be adjusted by the operator to a leading, unity, or lagging power-factor value. For any particular load a certain field current will make the motor operate at unity power factor. This value of field current is called normal excitation. A field current less than normal excitation will produce a lagging power factor, and a field current more than normal will produce a leading power factor.

172. A synchronous motor can be used to correct low power factor of the system that feeds it in addition to driving a mechanical load, provided it has sufficient capacity.

This characteristic is often of considerable importance. It is well known that the power factor of the induction motor, even under full-load conditions, is seldom greater than 95 per cent, and it often falls as low as 50 or 60 per cent at light load. The result is that an a-c generator driving a considerable number of induction motors ordinarily operates at a comparatively low power factor. If this alternator is loaded to its full kilowatt capacity at such a low power factor, overheating will result.

If the alternator is not loaded beyond its normal current capacity it operates at a low energy load but the with same heating losses as at full load, on account of the reduced power factor. The advantage of the synchronous motor on such a system is that by proper adjustment of its field current it may be made to draw from the line a current which is leading with respect to the voltage, and which will neutralize the lagging current taken by the induction motors. The current in the a-c generator can thereby be brought into phase with the voltage, and the generator will operate under its normal conditions. When used in this manner as a compensator for lagging current, the synchronous motor must be of

larger size than required by its power output, on account of the excess current which it draws from the line.

A synchronous condenser is a synchronous motor that operates to correct power factor only and does not pull any mechanical load.

173. Classification of Synchronous Motors.

1. According to power-factor rating.
   a. 1.0 (unity) power factor.
   b. 0.8 (leading) power factor.
2. According to speed.
   a. High speed.
   b. Low speed.
3. According to service.
   a. General purpose.
   b. Special purpose.

The horsepower ratings of synchronous motors are based on unity or 0.8-power-factor operation. A unity power-factor motor is designed to carry its rated horsepower load when operating at unity power factor. An 0.8-power-factor motor is designed to carry its rated horsepower load when operating at 0.8 power factor leading. Either a unity- or an 0.8-power-factor-rated motor can be operated at power factors below their rated amount provided that the horsepower output is reduced below the rated value a sufficient amount so that the machine will not be overheated.

Synchronous motors are divided into two groups according to the value of their rated speed. Motors with speeds of 500 r.p.m. or greater are called high-speed motors, and those with speeds below 500 r.p.m. are classed as low-speed motors.

174. National Electrical Manufacturers' Association Minimum-torque Values for Synchronous Motors

Horsepower and rated power factor	No. of poles	Speed, r.p.m.	Torques with rated voltage applied, percentage of rated full-load torque		
			Starting	Pull-in (based on normal external load WR^2)	Pull-out[a]
General Purpose					
1.0 power factor to and including 200 hp.	4	1,800	110	110	150
	6–14	1,200–514	110	110	175
0.8 power factor to and including 150 hp.	4	1,800	125	125	200
	6–14	1,200–514	125	125	250
Large High Speed					
1.0 power factor:					
250 to 500 hp	4–14	1,800–514	110	110	150
600 hp. and larger	4–14	1,800–514	85	85	150
0.8 power factor:					
200 to 500 hp	4–14	1,800–514	125	125	200
600 hp. and larger	4–14	1,800–514	100	100	200
Low Speed—Engine Type					
1.0 power factor, all sizes	16 and more	450 and below	40	40	150
0.8 power factor, all sizes	16 and more	450 and below	40	40	200
Low Speed—Compressor Type					
All			40	30	140

[a] With normal excitation.

175. General-purpose synchronous motors are rated on a 40°C. temperature-rise basis with a service factor of 1.15 (see Sec. **130**). When started with full voltage, these motors will have starting kva. inrushes of from 550 to 700 per cent of the motor's normal kva. rating. Normal torque values for these motors are given in Sec. **174**. The pull-in torques as given in Sec. **174** are based on the standardized normal WR^2 of load as given in Sec. **176**.

176. Normal WR^2 of Load for Synchronous Motors (Exclusive of Motor WR^2)

Rating, hp.	1,800 r.p.m.	1,200 r.p.m.	900 r.p.m.	720 r.p.m.	600 r.p.m.	514 r.p.m.
20	3.75	8.1				
25	4.63	10.5				
30	5.75	13	23.1			
40	8	18.1	32.1	50.2		
50	10.4	23.5	41.7	65.2	93.8	
60	12.9	28.9	51.3	80.2	115.5	
75	16.6	37.5	66.5	104	150	
100	23.1	52.2	92.6	145	209	284
125	29.9	67.2	119.5	186.5	268.5	366.5
150	36.9	83	147.5	230	331	452.5
200	51	115	205	320	460	627.5
250	66	149	264	412.5	594	810
300	82	184	327	512	736	1,005
350	98	220	391	612	880	1,200
400	113.5	255	455	711	1,024	1,388
450	129	290	516	807	1,165	1,586
500	147.5	330	587	920	1,325	1,800
600	181	408	725	1,130	1,625	2,225
700	217	487	865	1,350	1,950	2,650
800	253	568	1,010	1,575	2,275	3,100
900	289	650	1,160	1,813	2,600	3,550
1,000	328	738	1,312	2,050	2,950	4,025
1,250	422	920	1,686	2,640	3,800	5,175
1,500	522	1,172	2,090	3,265	4,700	6,400
1,750	622	1,400	2,490	3,890	5,590	7,625
2,000	725	1,625	2,890	4,525	6,512	8,875
2,250	832	1,875	3,325	5,200	7,500	10,250
2,500	935	2,100	3,725	5,840	8,400	11,450
3,000	1,160	2,610	4,650	7,250	10,470	14,250
3,500	1,375	3,100	5,525	8,625	12,450	17,000
4,000	1,612	3,630	6,440	10,060	14,500	19,750
4,500	1,840	4,130	7,350	11,500	16,550	22,500
5,000	2,090	4,680	8,325	13,000	18,750	25,500

177. Synchronous-motor Characteristics

Westinghouse Electric and Manufacturing Company

Torques with full voltage applied to motor, percentage of full-load torque			Starting kva., percentage of full-load kva.		Type of motor	Reduced-starting kva. methods, kva. per step in percentage of full-load kva.						
						Series reactor	Increment starters				Saturable core reactor	Auto-transformer
							Series resistor					
Starting	Pull-in	Pull-out	Full-voltage, squirrel-cage starting	Across-the-line, wound-rotor type starting			2 point	3 point	4 point	5 point		
Low Speed (450 r.p.m. and below)												
35–40	30–35	150	225	.....	Conventional	125	125					
40–50	40–50	150	275	.....	Conventional	150	150	100	.....	.....	.....	180
50	60–75	150	325–350	.....	Conventional	175	175	125	100			
80	110	150	475	.....	Conventional	250	250	175	125	100	100	
60	100	150	425	.....	Conventional	225	225	150	100			
100–125	50–60	150	400	.....	Conventional	.....	.....	.....	.....	.....	.....	175
100–125	100	150	500	.....	Conventional	.....	.....	.....	.....	.....	.....	325
50– 75	65	250–300	400–500	.....	Conventional	275–325						
80–100	100–110	250	475–500	.....	Conventional	300–400	300–400					
125–150	100	200–250	500–550	.....	Conventional							
150–200	100–125	175–250	550–700	.....	Conventional	.....	350–450	200–250	150–200	125–150	100–125	
150–200	100–125	175–250	.....	450–550	Single phase wound rotor							
150–200	100–125	175–250	.....	265–365	Three phase wound rotor							
High Speed (514–1,800 r.p.m.)												
50– 60	50–50	150–175	300–350	.....	Conventional							
80–100	50 60	150–175	350–400	.....	Conventional	175–250	175–250	125–150	100	.....	.....	150–200
60	100–110	150–175	400–450	.....	Conventional	200–250	200–250	150–175	100–125			
100–125	100	150–175	500	.....	Conventional	.....	.....	.....	.....	.....	.....	325
50– 75	65	250–300	400–500	.....	Conventional	275–325	275–325					
80–100	100–110	250	475–550	.....	Conventional	300–400	300–400					
125–150	100–110	250	500–550	.....	Conventional							
150–200	100–125	175–250	550–700	.....	Conventional	350–450	350–450	200–250	150–200	125–150	100–125	
150–200	100–125 (514–720 r.p.m.)	175–250	.....	450–550	Single phase wound rotor							
150–200	100–125 (900–1,800 r.p.m.)	150–200	.....	200–300	Wound rotor							

178. Special-purpose Synchronous Motors.—For applications where the characteristics of general-purpose motors do not fit the operating requirements, the manufacturer fits the design of the auxiliary windings and motor proportions to meet the qualifications of the specific applications. These custom-made motors are made with the following types of auxiliary windings:

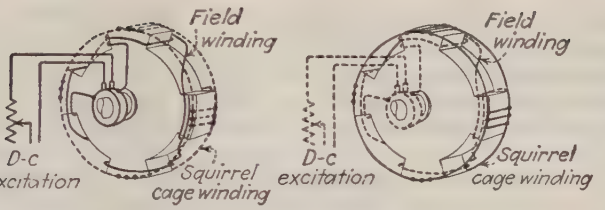
1. Conventional squirrel-cage winding.
2. Conventional squirrel-cage winding plus single-phase, wound-rotor winding.
3. Three-phase wound-rotor winding.

The fundamental connections and functioning of the different types of auxiliary windings are illustrated in Fig. 82.

By means of proper design of a conventional squirrel-cage winding the torque and starting-inrush-kva. characteristics may be varied over the limits given in Sec. **177.** Where higher starting torques with low starting kva. are required, a wound-rotor auxiliary winding is employed. For applications requiring a fairly high starting torque with fairly low starting-inrush kva., a single-phase, wound-rotor winding is added in addition to the conventional squirrel cage. For applications requiring exceptionally high starting torques with low starting kva., a three-phase, wound-rotor winding is employed. Motors with a wound-rotor auxiliary winding are started under full voltage with external resistance inserted in the auxiliary winding in the same manner as that used in starting wound-rotor induction motors.

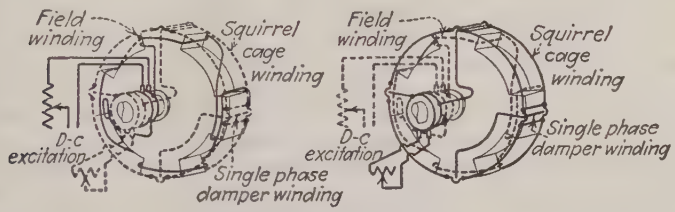
179. Supersynchronous Motors.—The General Electric Co. until recently manufactured a special type of synchronous motor for applications which require a very heavy starting torque and which require that the starting and accelerating currents be limited to moderate values. This motor was their Type TSR, called the supersynchronous motor. The motor is so constructed that the stator can revolve, while the rotor and load are at rest. After the stator has come up to speed, a large hand brake is gradually applied to it, bringing the rotor and load gradually up to speed. These motors will develop 200 per cent of full-load torque at starting.

180. Fynn-Weichsel Motors.—The Wagner Electric Corp. developed a special type of self-exciting synchronous motor called the Fynn-Weichsel motor. The rotor of this motor carries two windings, one a d-c winding connected to a commutator, and the other a three-phase winding connected to three slip rings on the opposite end of the shaft from the commutator. The stator also has two windings. The two stator windings are displaced 90 electrical degrees from each other. One of the stator windings is normally short-circuited, and the other is connected to the d-c brushes of the rotor. In starting, resistance is inserted in series with each of the stator windings as shown in Fig. 83, and the a-c rotor winding is connected directly across the line. During the starting period



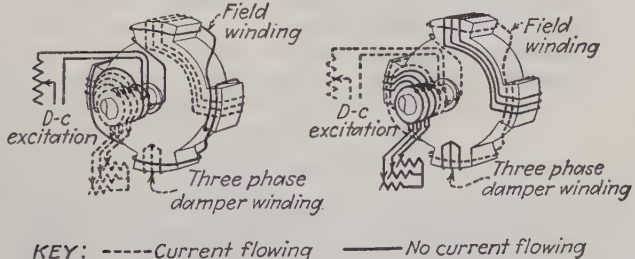
Start Run

Conventional design.—*Start*, motors start like standard induction motors—by means of squirrel cage windings embedded in the pole faces. *Run*, the motor comes up to speed and after a predetermined "definite time," the d-c field excitation is applied. This causes the motor to shift from induction to synchronous operation.



Start Run

High torque—low starting kva.—*Start*, motor gets high torques at start with low kva inrush, by a standard squirrel cage winding plus a separate series winding on the pole faces connected to an external resistor. *Run*, the motor comes up to speed and after a predetermined "definite time," the d-c field excitation is applied. This causes the motor to shift from induction to synchronous operation.



Start Run

High torque—starting kva 50 per cent or less of normal.—*Start*, motor starts like any ordinary 3-phase, wound rotor motor. The external resistor makes possible variable high torque together with extremely low starting kva. *Run*, the motor comes up to speed and after a predetermined "definite time," the d-c field excitation is applied. This causes the motor to shift from induction to synchronous operation.

FIG. 82.—Types of auxiliary windings for synchronous motors. (*Westinghouse Electric & Manufacturing Co.*)

the a-c rotor winding acts as the primary of an induction motor, and the two stator windings as the secondary of a wound-rotor induction motor with external resistance. The motor, therefore, starts as a wound-rotor induction motor with resistance in series with the secondary, thus producing good starting torque with a low value of starting current. The

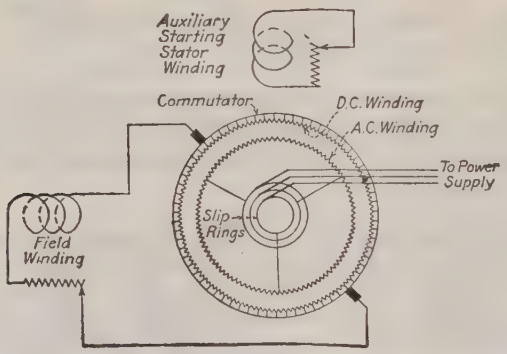


FIG. 83.—Diagram of Fynn-Weichsel motor—starting connections.

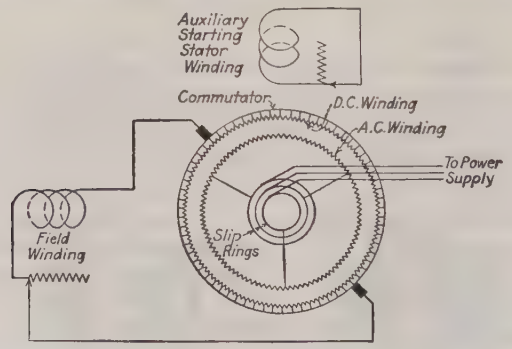


FIG. 84.—Diagram of Fynn-Weichsel motor—normal running connections.

starting current and torque can be adjusted by means of the resistances in series with the two stator windings. The maximum starting torque that these motors can develop is 250 per cent of the full-load torque. This maximum starting torque will require a current of approximately 330 per cent of the full-load current. Ordinarily the resistances are adjusted to produce about 150 per cent of full-load torque at starting, with a starting current of 200 per cent of the full load current.

As the motor comes up to speed, the resistances in the stator circuits are cut out, until one of the stator windings is short-circuited, and the other is connected directly in series with the d-c winding of the rotor, as

shown in Fig. 84. The motor then pulls into step as a synchronous motor. During the interval between induction and synchronous operation the torque developed is greater than the full-load rated torque. Under the normal running conditions the short-circuited stator winding carries no current, and the other stator winding carries direct current produced in the d-c rotor winding. The motor is a self-excited synchronous machine, the d-c rotor winding supplying the necessary excitation. It will operate thus as a synchronous motor at constant speed from no load to 150 per cent of rated load. If an excessive overload is placed on the machine, it will not stall as will the ordinary synchronous motor. When more than approximately 150 per cent load is placed on the Fynn-Weichsel motor, the machine pulls out of step as a synchronous motor but continues to run as an induction motor up to the pull-out torque of the motor. The pull-out torque is approximately 250 per cent of full-load torque.

181. The Fynn-Weichsel motor is not adapted for ordinary speed-control service. It may be operated, however, at speeds below normal for short periods of time. This is accomplished by the insertion of resistance in series with the two secondary (stator) windings just as in starting. Under these conditions the motor operates as a wound-rotor induction motor with resistance in series with the rotor winding. The allowable horsepower and efficiency are reduced approximately proportionally to the reduction in speed. When operating at reduced speed, the motor has a varying speed characteristic, the amount of variation of speed with change in load depending upon the amount of resistance inserted in the secondary circuit. When operating in this manner, the motor produces no power-factor corrective effect. This limited speed-control feature makes the Fynn-Weichsel motor suitable for certain types of service that require speed control during the starting period with constant speed under normal running conditions. On conveyors, for example, the motor can be run at various speeds, until all operations along the conveyors are speeded up to normal, after which the motor can be stepped up to synchronous speed.

182. The power factor of the Fynn-Weichsel motor depends upon the setting of the brushes and the load. The brushes generally are set at an angle of 25 to 30 deg. from the field axis. This setting of the brushes gives a leading power factor at all loads from no load to full load, the power factor being from 87 to 92 per cent at full load and from 40 to 60 per cent at no load. Greater power-factor corrective effects can be obtained by shifting the brushes more than 25 or 30 deg. from the field axis, but the allowable horsepower rating will be less than the normal horsepower rating. If the brushes are set on the field axis, the power factor is approximately 100 per cent from no load to full load. The Fynn-Weichsel motor may be operated as a synchronous condenser by setting the brushes approximately 90 deg. from the field axis. Under

this condition it will pull its full kva. rating at approximately 0 per cent leading power factor.

183. The repulsion motor (Fig. 85) has an armature which is like that of a d-c machine. It is provided with two brushes E_1 and E_2, which are inclined to the axis of the stator winding. These brushes are connected by a low-resistance conductor D, which short-circuits the armature. A machine of this type has a high starting torque with a small starting current, and a rapidly decreasing speed with increasing load, being similar in this respect to a d-c series motor. The power factor of the repulsion motor increases with the speed, and near synchronous

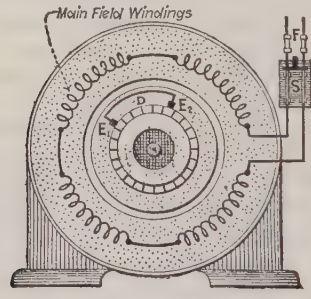


FIG. 85.—Diagram of repulsion motor.

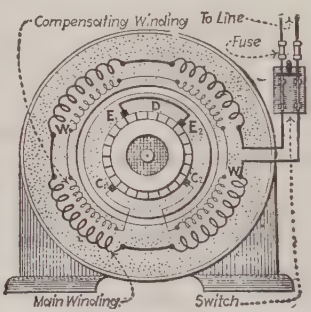


FIG. 86.—Diagram of compensated repulsion motor.

speed it attains a value much higher than is generally obtained in induction motors. These motors are used principally for constant-torque applications such as printing-press drives, fans, and blowers. The direction of rotation of a repulsion motor may be reversed by shifting the brushes to the reverse side of the neutral.

184. The compensated repulsion motor (Fig. 86) is similar to the repulsion motor, except that it has a compensating winding W and two compensating brushes C_1 and C_2, which the repulsion motor does not have. The compensating winding is wound on the stator. The compensating brushes are connected in series with the compensating winding. These motors have a starting torque equal to about 2½ to 3 times full-load torque with approximately twice full-load current. Owing to the corrective action of the compensating winding, the power factor is very high at all loads. However, the efficiency of this machine is lower than that of the induction motor. Single-phase motors of this type are well adapted for loads involving heavy starting torque and sudden overloads. For a more complete discussion of this type of motor see the author's "Electrical Machinery."

185. Brush-shifting Type of Single-phase Motor.—The brush-shifting, single-phase repulsion motor, as manufactured by the General Electric Co., is a compensated repulsion motor. It is an adjustable

varying-speed type of motor. The adjustment of speed is obtained by shifting the position of the brushes on the rotor. The speed may be controlled directly at the motor by means of a brush-shifting handle attached to the brush rigging. If it is desired to control the speed from some point remote from the motor, the brush-shifting handle may be connected to a pedestal or foot controller by means of a rocker-shaft assembly (bracket, rocker shaft, and levers). These motors may be obtained in $\frac{1}{4}$- to 3-hp. sizes for either reversing or nonreversing service. The motor is reversed by simply shifting the brushes in the opposite direction from the neutral point. The brush-shifting motor is a constant-torque motor. The rated horsepower is the allowable horsepower for the highest speed. As the speed is reduced, the allowable horsepower is reduced in proportion. A speed reduction of 3:1 is possible when operating against a constant torque of 75 per cent of the rated value. If operating against 100 per cent normal torque, a speed reduction of 4:1 can be obtained. The no-load speed is approximately 60 per cent above synchronous speed. At no load or with light loads very little speed reduction is possible. The starting torque of these motors with full voltage varies from 150 to 300 per cent of full-load rated torque for four-pole machines, and from 125 to 250 per cent for six-pole motors, depending upon the brush position.

The breakdown torque is more than 400 per cent of full-load rated torque when the brushes are in the maximum-speed position. As the brushes are shifted for the lower speeds the breakdown torque decreases. These motors are generally started with full voltage.

186. A single-phase induction motor, when its rotor is not revolving, has no starting torque. After the rotor commences revolving there is a certain interaction of magnetic fields whereby there is exerted a continuous turning effort. Single-phase induction motors are provided, therefore, with some auxiliary means for making them self-starting. Single-phase induction motors may be divided into the following groups, depending upon the method employed for starting:

1. Shading coil.
2. Inductively split phase.
3. Condenser split-phase or capacitor motor.
4. Repulsion start induction run.
5. Repulsion induction.

187. Shading-coil, Single-phase Induction Motors.—Some fractional-horsepower motors, principally those used on small ventilating fans, are made self-starting by means of the shading-coil method. The stator winding of these motors is not distributed around the frame, as in most induction motors, but is wound on projecting pole pieces, as in d-c machines. In addition to the main stator winding a short-circuited coil, or shading coil, as it is called, is placed around only a portion of the pole piece (Fig. 87). This shading coil makes the flux in the portion of the pole piece surrounded by it lag behind the flux in the other portion of the

pole. The shifting of the flux thus produced will develop sufficient torque to start small motors under very light load conditions. These motors are constant-speed machines. They are made in sizes of from $\frac{1}{250}$ to $\frac{1}{40}$ hp. and are used for driving small fans. For starting-current values refer to Sec. **190.**

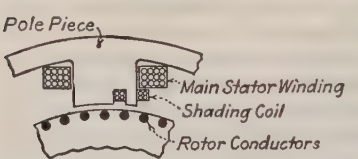


FIG. 87.—Construction of shading-coil motor.

188. The inductively split-phase, single-phase induction motor is provided with an auxiliary starting winding, in addition to the main stator winding. This winding is located in stator slots so that it is displaced 90 electrical degrees from the main stator winding, as shown in Fig. 88. If two currents sufficiently out of phase with each other are passed through the main and auxiliary windings, conditions similar to

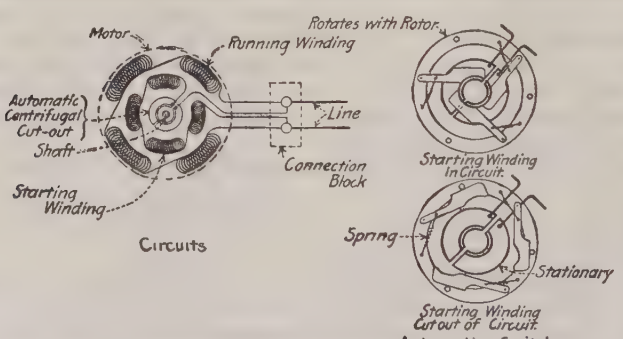


FIG. 88.—Single-phase motor diagram.

those existing in a two-phase induction motor will be produced. The necessary two currents, which are from 30 to 45 degrees out of phase with each other, are obtained from the single-phase supply by constructing one of the circuits with a relatively high inductance, and the other with a relatively high resistance. The main or running winding is normally of high inductance at the time of starting. The auxiliary winding is wound with finer wire, making it have higher resistance than the main winding. The running winding remains in the circuit at all times of operation, while the starting winding remains in the circuit only until the motor has reached 50 to 80 per cent of synchronous speed. When the speed is reached at which the starting winding should be cut out, an automatic centrifugal switch (see illustration) operates and opens the "starting" circuit. This type of single-phase induction motor thus starts as a two-phase machine, until the starting winding is cut out, when it continues to operate, by virtue of the running winding only, as a single-phase motor.

These motors are constant-speed machines, not adapted for any speed

control. They are made in sizes up to ½ hp. and in two types, the general-purpose type and the high-torque type. The general purpose type of motor has the following characteristics: full-voltage starting torque 75 to 175 per cent of full-load torque, full-voltage starting current within National Electrical Manufacturers' Association specifications of Sec. **190**, breakdown torque 175 to 225 per cent of full-load torque, and pull-up torque 75 to 200 per cent of full-load torque. They are suitable for full-voltage starting on any power system.

The high-torque type of motor has the following characteristics: full-voltage starting torque 150 to 275 per cent of full-load torque, full-voltage starting current approximately 850 per cent of full-load current, breakdown torque 225 to 350 per cent of full-load torque, pull-up torque 225 to 325 per cent of full-load torque. The full-voltage starting currents exceed the N.E.M.A. specifications of Sec. **190** and may not be permissible for some installations.

189. National Electrical Manufacturers' Association Minimum Torques for Inductively Split-phase Motors

Hp.	Torques in percentage of rated full-load torque					
	Locked rotor		Pull-up		Breakdown	
	1,725 r.p.m.	1,140 r.p.m.	1,725 r.p.m.	1,140 r.p.m.	1,725 r.p.m.	1,140 r.p.m.
⅓	150	125	150	125	200	175
⅙	150	125	150	125	200	175
¼	90	75	90	75	185	175

190. National Electrical Manufacturers' Association Maximum Locked-rotor Currents for Inductively Split-phase Motors

Hp.	Locked-rotor currents in amp. for rated voltages of	
	110 volts	220 volts
Up to ⅙	20	10
¼	23	11.5
⅓	31	15.5
½	45	22.5
¾	61	30.5

191. Capacitor motors are single-phase induction motors which have two stator windings displaced 90 electrical degrees from each other just the same as the inductively split-phase motor. Therefore they have starting torque developed by two-phase action. In the capacitor motor the necessary phase displacement between the currents of the two stator windings is produced by placing a condenser in series with the auxiliary winding. By this means the phase displacement can be made more nearly 90 degrees, which results in better starting torque with lower starting current than can be obtained with the inductively split-phase-started motor. Capacitor motors are available in the following types:

1. Capacitor start, induction run.
2. Capacitor start, capacitor run.
   a. Two-value capacitor (high torque).
   b. Single-value capacitor (low torque).
3. Multispeed, capacitor start, capacitor run.

Capacitor motors have the advantages of quiet operation, high power factors, and reduction in radio interference.

192. The capacitor-start, induction-run motor starts by two-phase action. After the motor has reached approximately 75 per cent of full-load speed, a centrifugal switch opens the auxiliary circuit, and the motor continues to run as an ordinary single-phase induction motor. A diagram for a motor of this type is shown in Fig. 89. These motors develop starting torques of from 275 to 400 per cent of rated full-load torque. The breakdown torque is from 200 to 300 per cent of rated full-load torque. Their starting currents are sufficiently low so that they are started with full voltage. Motors of this type are made in sizes of from ⅛ to ¾ hp.

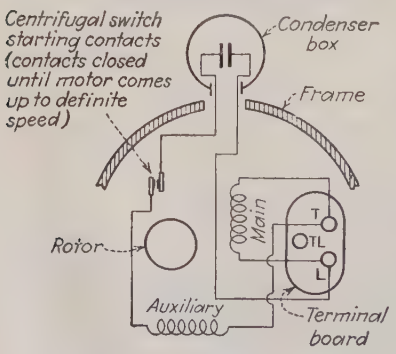


FIG. 89.—Connection diagram of capacitor-start, induction-run motor. (*Wagner Electric Corp.*)

193. Capacitor-start, capacitor-run, single-phase induction motors utilize both of the stator windings at all times. The motor secures its power from a single-phase supply but really operates both when starting and running as a two-phase motor. For the **two-value capacitor motor** a larger value of capacity is used during the starting period than is employed for running conditions. The larger capacity for starting may be obtained by means of an additional capacitor (Figs. 90 and 91) or

through changing the connections to an autotransformer which supplies the power to a single capacitor (Fig. 92). For small motors the change in the connections between starting and running is performed by means of a

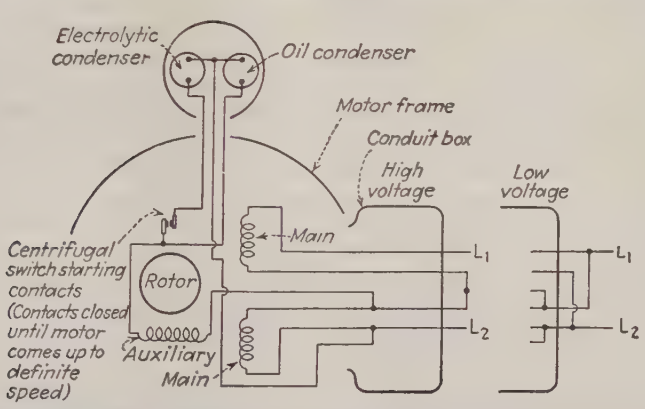


FIG. 90.—Connection diagram for two-value capacitor motor (capacitor-start, capacitor-run) with centrifugal switch. (*Wagner Electric Corp.*)

centrifugal switch (Fig. 90), while for larger motors a definite time relay is employed (Fig. 91). The two-value capacitor motor produces a high starting torque of from 275 to 450 per cent of rated full-load torque with starting currents that are in most cases sufficiently low so that they may be started with full voltage. The breakdown torques will be from 200 to 300 per cent of rated full-load torque. These motors are available in sizes of from ⅛ to 10 hp.

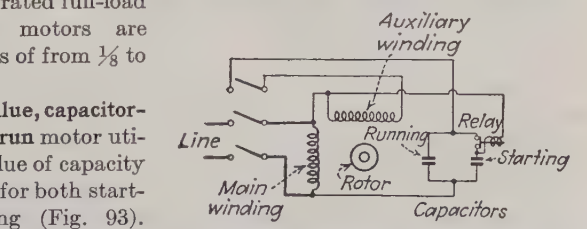


FIG. 91.—Connection diagram for two-value capacitor motor (capacitor-start, capacitor-run) with acceleration relay. (*General Electric Co.*)

The **single-value, capacitor-start, capacitor-run** motor utilizes a single value of capacity that is the same for both starting and running (Fig. 93). There is no change in connections between the starting and running condition. These motors have low starting torques of a value between 40 to 60 per cent of rated full-load torque. The breakdown torques will be from 150 to 200 per cent of rated full-load torque. The starting current will generally be sufficiently low for full-voltage starting. These motors are made in sizes of from ⅛ to 10 hp.

The principal advantage of the capacitor-start, capacitor-run motors

over the capacitor-start, induction-run motors is that they operate at a higher power factor.

194. Multispeed capacitor motors are single-value, capacitor-start, capacitor-run motors equipped with a selector switch and autotransformer for supplying different voltages to the main winding. They are suitable only for special classes of services since the breakdown torque is reduced in proportion to the square of the voltage impressed on the main winding. It is possible to provide the motor with a centrifugal switch so that when properly connected it is impossible to start the motor except with full voltage impressed upon the main winding.

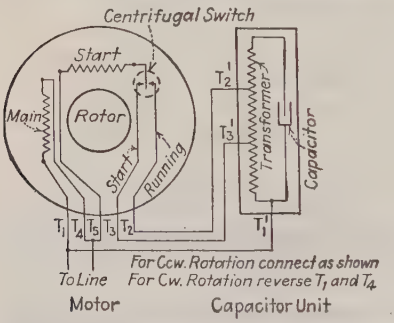


FIG. 92.—Diagram for a high-starting-torque capacitor motor. (*General Electric Co.*)

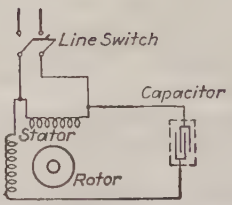


FIG. 93.—Diagram for a low-starting-torque capacitor motor. (*General Electric Co.*)

195. Repulsion-start, Induction-run, Single-phase Motors.—Single-phase induction motors which are started by repulsion-motor action are constructed similarly to the straight repulsion motor with the addition of a centrifugal device which shorts the commutator segments after the motor has come up to speed. The motor starts as a repulsion motor, but, after it has come up to the required speed so that the commutator segments are short-circuited, it operates as a straight-induction motor. These motors are constant-speed machines not capable of speed control. The starting torques of different motors vary from 300 to 500 per cent of the full-load torque. The breakdown torque is at least 175 per cent of the full-load torque. The starting currents of these motors vary from 200 to 350 per cent of full-load current, so generally they may be started directly across the line. When it is necessary or desirable to limit the starting current to smaller values, a resistance type of starter is employed. They are made in sizes of from ⅛ to 15 hp.

196. The repulsion-induction motor has two rotor windings. One of these windings is an ordinary induction rotor winding, and the other is a repulsion winding connected to a commutator with short-circuited brushes. There is frequently a compensating winding on the stator

connected to brushes bearing on the commutator, as discussed in Sec. **184.** This motor starts by repulsion-motor action. Since there is no short-circuiting device, after the machine has come up to speed both the repulsion and the induction windings are active. Under running conditions the motor functions as a combined induction and repulsion motor. The starting torque with rated voltage impressed for different sizes and speeds varies from 225 to 300 per cent of the full-load torque. There is no definite breakdown point, the maximum torque occurring at standstill. The starting currents of these motors, when thrown directly across the line, are within the requirements of most power companies. When it is desired to limit the starting currents to smaller values, a resistance type of starter is employed. The repulsion induction motor is a constant-speed machine with a speed variation from no load to full load of about 6 per cent. Its speed cannot be adjusted. They are made in sizes of from ½ to 10 hp.

197. The single-phase series or "universal" motor (Fig. 94) comprises an armature of the d-c type connected in series with the field. It will operate successfully on either a-c or d-c circuits. The single-phase series motor finds its widest application in the fractional-horsepower services such as those for fans, appliance motors, and electric drills. These machines have approximately the same speed-torque characteristics as the d-c series machines. In the larger capacities, single-phase series motors are equipped with compensating windings which compensate for the armature reaction. The compensating winding is placed in the pole face and must be so connected that at any instant the current will flow in the same direction in all the conductors under any one pole. The compensating winding may be connected in series with the armature. When so connected it is called a conductively compensated winding. The compensating winding may be short-circuited on itself. When thus arranged it receives its current by induction, and the machine is said to be inductively compensated.

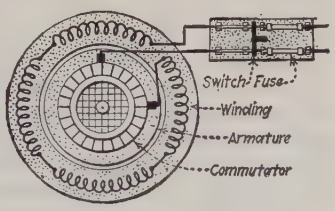


FIG. 94.—Diagram of a series or universal motor.

198. Methods of Reversing Motors.—In the following paragraphs instructions are given for reversing the different types of motors.

Direct-current Shunt or Series Motors.—Interchange the connections of either the field or the armature winding. Reversing the line leads will not change the direction of rotation. If the motor is not equipped with commutating poles, the brushes should be shifted to the same position on the opposite side of the neutral axis.

Direct-current Compound Motors. Method 1.—Interchange the connections of the two armature leads.

Method 2.—Interchange the connections of the two shunt-field leads and also interchange the connections of the two series-field leads. Interchanging the connections of just the two shunt-field leads will change the direction of rotation, but the motor would then operate as a differential compound motor instead of cumulative. If the motor is not equipped with commutating poles, the brushes should be shifted to the same position on the opposite side of the neutral axis.

Any Four-wire, Two-phase Induction Motor.—Interchange the connections to the line of the two leads of either phase.

Any Three-wire, Two-phase Induction Motor.—Interchange the connections to the line of the two outside wires.

Any Three-phase Induction Motor.—Interchange the connections to the line of any two leads. In reversing the commutator type of polyphase induction motor the brush-shifting mechanism must be adjusted to the proper position for the reversed rotation in addition to reversing the connections of two of the line leads.

Synchronous Motors.—Ordinary synchronous motors are reversed in the same manner as induction motors.

Fynn-Weichsel Motors.—Interchange the connections to the line of any two of the motor leads and shift the commutator brushes to the same position on the opposite side of the field axis.

Single-phase Induction, Shading-pole Starting.—The direction of rotation cannot be reversed except in special cases. If the pole pieces of the machine can be removed, then the direction of rotation can be reversed by revolving the pole pieces 180 deg. on their own axes. This will place the shading coils on the opposite sides of the pole pieces. Some special motors are built with shading coils on both sides of the pole pieces. With these machines, each shading-coil circuit must be provided with a switch. The direction of rotation depends on which shading-coil circuit is closed.

Single-phase Induction, Inductively Split-phase Starting.—Interchange the connections of either the main or the auxiliary winding.

Single-phase Capacitor Motor.—Interchange the connections of either the main or the auxiliary winding.

Single-phase Induction, Started by Repulsion Action.—Shift the brushes to the same position on the opposite side of the neutral axis.

Single-phase Repulsion Motor.—Shift the brushes to the same position on the opposite side of the neutral axis.

Single-phase Series Motor.—Reversed in the same manner as d-c series motors.

198A. Electric-motor Braking.—Braking of electric motors may be performed by (1) friction braking, (2) plugging, (3) dynamic braking, or (4) regenerative braking.

Friction braking of electric motors consists of retarding the motor speed or of completely stopping the motor by means of a solenoid-operated friction brake of the shoe or disk type.

Plugging is the method of retarding the motor speed and completely stopping the motor or of reversing the motor by the application of electric power in the reverse direction so that the motor develops torque in the opposite direction to the direction of rotation. Plugging will quickly bring a motor and its driven load to a stop. If the reverse power is not removed when the motor comes to a stop, the motor will reverse and accelerate in the opposite direction.

Dynamic braking is the method of retarding the motor speed or of completely stopping the motor through making the motor act as a generator with a resistance load.

Regenerative braking is the method of retarding the motor speed by making the motor, functioning as a generator, feed its generated power back into the supply line. Regenerative braking will not stop the motor. It is effective only for braking of overhauling loads. Overhauling loads are those which attain a speed greater than that of the motor speed-load characteristic and under which, therefore, the load tends to drive the motor.

198B. Plugging of Motors.—To employ plugging retardation of electric motors, a reversing switch or contactor must be provided in the control equipment. In order to stop or retard the speed of the motor by plugging, the conections to the power supply are simply reversed in the proper manner so that the motor develops torque in the opposite direction to that in which it is rotating. For squirrel-cage induction motors, the braking action may be cushioned so as to reduce the shock to the machine and power system by the use of resistance connected in series with the reversed connections to the supply. For wound-rotor induction motors, the plugging torque can be controlled by adjustments of the resistance in the motor secondary circuit. For synchronous motors, the d-c field circuit is de-energized during the plugging operation, and the motor is plugged in the same manner as a squirrel-cage induction motor. For d-c motors, additional resistance must be used in series with the reversed power connections. When it is imperative that the motor come to a stop without reversal, a zero-speed switch or a timing relay must be used to open the motor circuit when the machine comes to a stop.

Advantages:

Simple arrangement and installation.

Fast operating performance.

Free to rotate after stopping in contrast to mechanically set brake.

No friction parts and freedom from maintenance.

Suitable for large motors and severe duty.

Disadvantages:

Requires reversing controller.

Requires zero-speed switch or consistent timing relay if reversing is to be prevented.

Power must be available. Cannot plug if power fails.

Power system must be capable of supplying the peak plugging current. Motor windings may require special bracing.

If motor and its load must positively be held stationary when the motor is de-energized, then additional spring-set or other type of mechanical brake is necessary.

198C. In dynamic braking, the armature of the motor is disconnected from the power supply, and the load will drive the motor as generator. The generator action is loaded either through resistance banks or through a part of the motor winding. For d-c shunt or compound motors, the armature is disconnected from the line and connected to a resistor bank. The shunt field is left connected to the supply line. For d-c series motors, the machine is disconnected from the supply, and the armature and series-field circuits are segregated from each other. The field winding is connected in series with the proper limiting resistance to the supply line. The armature is connected to a resistor bank load. Emergency dynamic braking of series motors can be accomplished by disconnecting the motor from the line, reversing the interconnection between the series field and armature, and then connecting the two in series to a resistor bank load.

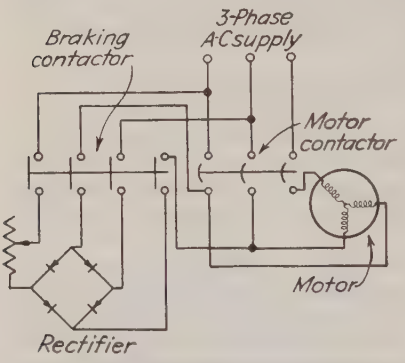


FIG. 94A.—Dynamic braking of induction motor with rectified direct current.

For dynamic braking of squirrel-cage induction motors, a source of excitation must be provided. Three methods of providing this excitation are (1) from a separate source of direct current, (2) from the a-c supply through a rectifier, and (3) by means of capacitors. In the first method, dynamic braking is accomplished by disconnecting the motor from the supply and connecting one phase of the motor primary to a separate source of direct current. The motor will then be driven by the load as a generator and will load itself through the induced current in the motor secondary flowing through the squirrel-cage winding. The d-c excitation must be removed at the end of the braking period, or the windings will overheat. In the second method, dynamic braking is accomplished in the same manner as in the first method except that the d-c supply for the excitation is obtained from the a-c supply through a single-phase rectifier. The rectifier is usually of the contact, or barrier-layer, type. A diagram of the connections required is shown in Fig. 94A. In the third method, a capacitor is permanently connected across the motor terminals. In braking, the motor is disconnected from the supply. The capacitor will

supply the motor with excitation so that it will function as an induction generator. The braking action is produced by the power losses inside the machine. Improvement of the braking action can be obtained by connecting a loading resistor in parallel with the capacitor. The larger the capacitor the greater will be the braking action. All braking action ceases with this method at about one-third of synchronous speed.

For wound-rotor induction motors, dynamic braking could be accomplished by all three of the methods just described for squirrel-cage motors. However, the first method, using a separate source of direct current for excitation, is usually the only one that is feasible. The amount of the braking action can be controlled through adjustment of the secondary resistance. For synchronous motors, dynamic braking is accomplished by disconnecting the motor armature from the a-c supply and connecting the armature to a resistor bank load. The field is left excited from direct current.

Advantages:

Cannot reverse the motor. No zero-speed switch or other antireversing device is required.

Smooth, positive retardation without the shock of mechanically set brake and less severe than plugging.

Braking torque easily adjustable by varying the d-c excitation or, as in wound-rotor induction-motor applications, by varying the motor secondary resistors.

In dynamic braking of small a-c motors by use of capacitors, the braking is independent of the power supply; furthermore, the capacitor furnishes power-factor correction while the motor is operating.

Disadvantages:

Requires source of d-c excitation during the braking period, except in capacitor braking.

Braking not available if exciting source fails.

More expensive and more complicated than plugging. If the source of excitation is not already available, and it is necessary to install additional equipment, the extra cost may be prohibitive.

Control must provide means for disconnecting the excitation at the expiration of the braking period.

Useless as a holding force after motor has come to rest and is deenergized.

Capacitor dynamic braking is ineffective and ceases to exist below approximately one-third speed; therefore, it is of little value except on drives involving considerable friction. Cost of capacitor braking is prohibitive with large motors.

Rectifier-excited dynamic braking is impracticable and expensive for large motors.

198D. Regenerative braking cannot be used for stopping a motor. It will produce braking action only when the load overhauls the motor

and drives the motor at a speed above the speed-load characteristic of the motor. When a load overhauls its drive motor, except for series d-c motors, the voltage generated in the machine will be greater than the supply-line voltage. Consequently the motor will function as a generator and feed power back into the supply line. This is an inherent characteristic of the motor and does not require any changing of connections or control equipment. If a series d-c motor is overhauled by its load, the motor loses its excitation and becomes incapable of regenerative braking unless the connections are changed. Therefore, to use regenerative braking on a series motor, the series field and armature must be segregated from each other and connected individually to the supply. Sufficient resistance must be connected in series with the series field so that the current will be held to normal value.

Advantages:

No extra equipment is required except for series-wound d-c motors. Can be made effective with d-c motors at reduced speeds by strengthening the motor field, *i.e.*, by lowering the speed at which the motor will regenerate.

Disadvantages:

Effective only at overhauling speeds. Useless as a means of stopping.

Where d-c motors must be made to regenerate at low speeds, the control becomes involved and expensive. The motor may require special fields.

CONVERSION EQUIPMENT

199. The conversion of alternating current to direct current is usually effected with a motor generator set, a synchronous converter, an electronic rectifier, or a contact (barrier-layer) rectifier. A discussion of electronic rectifiers is given in Div. 6. Contact rectifiers are discussed in Div. 4.

200. A motor generator set consists of a motor mechanically coupled to and driving one or more generators. The motor is usually alternating current and is mounted on the same bedplate and on the same shaft with the generator or generators which it drives. A motor generator set may be employed to convert electrical energy from one voltage or frequency to another voltage or frequency, to convert alternating current to direct current, or to convert direct current to alternating current. Where an a-c motor is used, it may be of either the induction or synchronous type. The induction type has the advantages of low first cost and rugged construction. It may also be wound for voltages as high as 13,500 volts. This will, in many cases, eliminate the necessity for transformers. It has, however, poorer speed regulation and lower power factor. A synchronous-motor drive is probably more frequently used for large-capacity installations than is the induction motor. The synchronous motor is inherently a constant-speed motor. Therefore by its use a more nearly constant voltage can be maintained at the generator terminals than

by the use of an induction motor. The field of the synchronous motor may be overexcited. It then acts as a synchronous condenser, thus improving the power factor.

201. A synchronous converter (sometimes called a rotary converter) for converting alternating to direct current or vice versa, consists (Fig. 95) of a d-c motor equipped with slip rings. Taps are brought out from equidistant points on the armature winding and connected to these slip rings. As ordinarily used the machine is then driven as a synchronous motor, by an alternating e.m.f. which is impressed on the armature through the slip rings. As the armature rotates, an alternating e.m.f. is induced in the armature winding, as in any d-c generator. This alternating induced e.m.f. is rectified by the commutator and leaves the brushes as a pulsating or direct current. If a synchronous converter is utilized for converting alternating current to direct current, it is called a **direct converter,** or merely a converter. If it converts direct current to alternating current, it is called an **inverted converter.** If the main-pole flux distribution is such that the induced e.m.f. has a sine-wave form, then (see Table 202 for values)

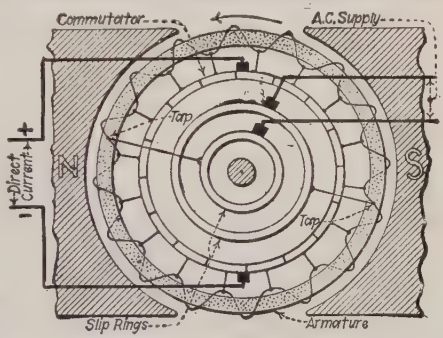


FIG. 95.—Diagram of two-pole single-phase synchronous converter.

$$\frac{E_{ac}}{E_{dc}} = 0.707 \left(\sin \frac{180}{n}\right) \tag{6}$$

wherein E_{ac} = the effective a-c voltage, in volts between adjacent slip rings; E_{dc} = the d-c voltage, in volts, and n = number of slip rings for a bipolar machine, or the number of taps per pair of poles for a multipolar machine.

202. Ratio of the Effective A-c to D-c Voltage with Different Numbers of Taps

Number of taps per pair of poles	Number of phases	$\frac{E_{ac}}{E_{dc}}$ (between adjacent taps)	$\frac{E_{ac}}{E_{dc}}$ (line voltage)
2	1	0.707	0.707
3	3	0.612	0.612
4	4 or 2	0.500	0.707
6	6	0.354	0.707 (diametrical) 0.612 (double Δ)
12	12	0.183	0.682 (double chord)

NOTE.—Synchronous converters are subject to hunting. The cause of hunting and the remedy are the same as for a synchronous motor.

203. The methods of starting a synchronous converter are (1) from its d-c side as a shunt motor, (2) by means of an auxiliary motor mounted on its shaft, and (3) if polyphase, from its a-c side as an induction motor. Whatever method is used the armature must be brought up almost to synchronous speed before the load is applied to the generator.

204. Usual Relation between Number of Poles, Phases, Taps, and Slip Rings of a Synchronous Converter

Phases	2 pole		4 pole		6 pole		8 pole		12 pole	
	Slip rings	Taps	Slip rings	Taps	Slip rings	Taps	Slip rings	Taps	Slip rings	Taps
1	2	2	2	4	2	6	2	8	2	12
2	4	4	4	8	4	12	4	16	4	24
3	3	3	3	6	3	9	3	12	3	18
6	6	6	6	12	6	18	6	24	6	36

NOTE.—The tendency of modern practice in large three-phase conversion installations is to use a six-phase converter. It is connected to the three-phase line through a set of transformers.

205. The relation between the values of direct and alternating current of any synchronous converter is

$$I_{dc} = 0.354 \times (I_{ac}) \times (n) \times (\text{power factor}) \times (\text{efficiency}) \qquad (7)$$

where I_{dc} = direct current, in amperes; I_{ac} = effective alternating current, in amperes, and n is as given in formula (6).

206. A frequency-changer motor generator consists of an a-c generator or generators driven by an induction or a synchronous motor or motors. The frequency of the generator is different from that of the motor. Since the speed regulation of the induction motor is inherently poorer, a synchronous driving motor is usually applied. The output frequency of a set which is driven by a synchronous motor will vary only with the input frequency and not with the load. The synchronous motor may also be utilized for improving the power factor of the energy-supplying system. Since the motor and the generator are mounted on the same shaft, and hence rotate at the same speed, the desired frequency change must be obtained by a proper ratio between the number of motor poles and the number of generator poles. The ratio between the frequency applied to the motor and the frequency which the generator will supply is exactly equal to the ratio between the number of poles on the motor and the number of poles on the generator. That is,

$$\frac{\text{No. of poles on motor}}{\text{No. of poles on generator}} = \frac{\text{frequency applied to motor}}{\text{frequency supplied by generator}} \qquad (8)$$

For 60- to 25-cycle conversion this practically limits the speed to 300 r.p.m. with 24 poles on the 60-cycle machine and 10 poles on the 25-cycle machine.

TROUBLES OF A-C MOTORS AND GENERATORS—THEIR LOCALIZATION AND CORRECTION

207. Troubles of A-c Machinery.—Much of the material under this heading is based on that in the book "Motor Troubles," by E. B. Raymond. For further data relating to a-c machinery troubles and their correction see the author's "Electrical Machinery."

208. Induction Motor Troubles (H. M. Nichols, "Power and the Engineer").—The author asserts that the unsatisfactory operation of an induction motor may be due to either external or internal conditions. The voltage or the frequency may be wrong, or there may be an overload on the machine. Low voltage is the most frequent cause of trouble. The starting current sometimes amounts to twice the running current, with the result that the voltage is particularly low at starting. The best remedy for this disorder is larger transformers and larger motor leads, one or both. The troubles that occur most frequently within the motor itself are caused by faulty insulation and by an uneven air gap due to the springing of the motor shaft or to excessive wear in the bearings. If a wound-rotor machine refuses to start, the trouble may be due to an open circuit in the rotor winding. Most wound-rotor motors designed to employ a starting resistance will not start at all if the resistance is left out of the secondary circuit with the secondary circuit open. A short-circuited coil in the motor will make its existence known by local heating in the latter.

209. Troubles of A-c Generators (Westinghouse Instruction Book).—The following causes may prevent a-c generators from developing their normal e.m.f.:

The speed of the generator may be below normal.

The switchboard instruments may be incorrect, and the voltage may be higher than that indicated, or the current may be greater than is shown by the readings.

The voltage of the exciter may be low because its speed is below normal, or its series field is reversed, or part of its shunt field is reversed or short-circuited.

The brushes of the exciter may be incorrectly set.

A part of the field rheostat or other unnecessary resistance may be in the field circuit.

The power factor of the load may be abnormally low.

210. Causes of Shutdowns of Induction Motors.—Sometimes there is trouble from blowing fuses. Or possibly, and more serious, the fuses do not blow, and the motor, perhaps humming loudly, comes to a standstill.

Under these conditions the current may be ten times normal, so that the heating effect, being increased as the square of the current or a hundredfold, causes the machine to burn out its insulation.

Since the torque or turning power of an induction motor is proportional to the square of the applied voltage (one-half voltage produces only one-quarter torque), it is evident that lowering the voltage has a decided effect upon the ability of the motor to carry load and may be the cause of its stopping. Another cause may be that the load on the motor is more than equal to its maximum output.

The bearings may have become worn, so that the air gap (which ordinarily is not much over 0.040 in. and on small motors may be as small as 0.015 in.) has been gradually reduced at the lower side of the rotor to practically zero. The rotor commences to rub on the stator. The friction soon becomes so great that it is more than the motor can carry. The result is that it shuts down.

A shutdown may be due to bearings introducing excessive friction. Hot bearings, in turn, may be due to excess of belt tension, dirt in the oil, oil rings not turning, or to improper alignment of the motor to the machine that it drives. Hence, under such conditions, it should be ascertained whether the voltage has been normal, whether the air gap is such that the armature is free from the field, and whether the load imposed upon the motor is more than that for which it was designed. In any installation a system should be arranged whereby an inspector will examine the gap, bearings, etc., periodically.

Rarely, shutting down may be due to the working out of the starting switch, which may be located within the armature. Such a switch is operated by a lever engaging a collar which bears on contacts which, as they move inward, cut out the resistance which is in series with the rotor winding and is located within it.

If the short-circuiting brushes work back, introducing resistance into the armature circuit while the machine is trying to carry load, it will at once slow down in speed and probably stop, usually burning out the starting resistance. Of course, this can occur only from faulty construction. The remedy is to fit the brushes properly, so that they will not work out. It is well to inspect them at the time of air-gap inspection.

211. Low Torque while Starting Induction Motors.—Although the circuit to the motor be closed, sometimes it does not start. The same general laws of voltage, etc., apply to the motor at starting as when running. Hence, the points mentioned under Shutdowns should be investigated and if necessary corrected. The resistance, which is frequently inserted in the armature, may be short-circuited, thus giving a low starting torque. With a wound-rotor motor it is necessary, in order to obtain a proper starting torque with a reasonable current, that a resistance be inserted in the rotor circuit. The resistance not only limits the current, which would, with the motor standing still, be large, but it causes the

current of the armature to assume a more effective phase relation, so that with the same current a far larger torque is obtained. A partial or complete short-circuit of the resistance will reduce the starting torque.

212. Low Maximum Output of Induction Motors.—The maximum load which a motor can carry may be less than desired or less than the name plate indicates. This may be due to improper interconnection of the motor windings or to low line voltage. If the line voltage is considerably below the rated voltage of the motor, the maximum torque that the motor can develop may be so reduced that the motor will stall on small overloads. Many motors are designed for operation at two voltages, for example, 110/220 or 220/440. This is accomplished by dividing the stator winding into two parts. For operation on the low-voltage rating the two parts of the winding should be connected in parallel, while for operation on the high-voltage rating the two parts should be connected in series. Sometimes, in putting a motor in service on a supply which has a voltage corresponding to the low-voltage rating of the motor, the windings are connected in series. With this connection the motor would be operating at half rated voltage. This wrong connection will be indicated by the motor's starting very slowly, or failing to start, or by stalling without overheating and without tripping the overcurrent devices.

213. Winding Faults of Induction Motors.—When a new induction motor is received, it sometimes happens that, when an attempt is made to operate the machine, although it will start, the currents are excessive and unbalanced, undue heating appears, or a peculiar noise is emitted, accompanied possibly by dimming of the lights on the same circuit and the lowering of speed, with perhaps actual shutdown of other induction motors thereon. If, after examination, there is found to be no difficulty with the air gap, belt tension, starting resistance, or bearings, the probabilities are that the coils of the motor have been wrongly connected or that the winding has been damaged during transportation. Certain indications of these conditions are shown by instrument readings. The winding faults in a three-phase motor may be:

1. One coil of the rotor may be open-circuited. The armature or rotor may have a defective winding just as may the stator.
2. Two coils or phases of the armature may be open-circuited.
3. Armature may be connected properly, but stator coil or phase may be reversed.
4. Part of stator may be short-circuited.
5. One phase of stator may be open-circuited.

214. With an open circuit in field or stator in a three-phase motor, current would flow only in two legs. There would be no current in the other leg, and the motor would not start from rest with all switches closed. However, a three-phase motor or a two-phase motor will run

and do work single-phase if it is assisted in starting. The starting torque is zero, but as the speed increases the torque increases.

With a small motor, giving a pull on the belt will introduce enough torque so that it will pick up its load. Therefore while an open circuit in the field winding should be found and repaired, if there is not time for repairs, the motor can be operated single-phase to about two-thirds of normal load. The power-factor conditions and effects on the rest of the circuit are practically no worse than when the motor is running three-phase. The torque of a 1-hp., three-phase induction motor from rest to synchronism, when running single-phase, is indicated in Fig. 76.

215. Squirrel-cage Armature or Rotor Troubles.—Unusual operation due to reversals of phase, phases open-circuited, and other causes occur with squirrel-cage armatures as well as with wound armatures. Poor soldering of the armature bars may be the cause. Sometimes a solder flux that will ensure proper operation for a while may be used, but time will develop poor electrical contacts due to chemical action at the joints. If the resistances of all the squirrel-cage joints are uniformly high, the effect is simply like that of an armature having a high resistance, which causes a lowering of the speed and local heating at the joints. If some of the joints are perfect, but some bad, the motor may not have the ability to come up to speed, and there will be unbalanced currents.

216. Effects of Unbalanced Voltages on Induction Motors.—The maximum output of a polyphase induction motor may be materially decreased if the voltages impressed on the different phases are unequal. On a three-phase system the three voltages between the legs 1–2, 2–3, and 1–3 should be approximately equal. Also on a two-phase system the voltage 1–2 should equal 3–4. If these voltages impressed on the induction motor are not equal, the maximum output of the motor as well as the current in the various legs is proportionately affected.

For example, with a two-phase motor, if the voltages in the two legs differ by 20 per cent, a condition sometimes met in normal practice, the output of the motor may be reduced 25 per cent. Then, instead of being able to give its maximum output of, say, 150 per cent for a few moments, it will give but 112 per cent. The varying loads which the motor may have to carry may shut it down. In cases of low maximum output, the relative voltages on the various legs should always be investigated. If they vary, the trouble may be due to this variation.

In addition to the effect on the maximum output, the unequal distribution of current in a two-phase motor under such conditions may be quite serious. Consider a specific case of a 15-hp. six-pole., 1,200-r.p.m., 220-volt motor, with the voltage on one leg 220 and the voltage on the other leg 180; current in leg 1 was 60 amp. and in leg 2 was 35 amp. at full load. The normal current at full load was 35 amp. Thus the fuse might blow in the phase carrying the high current, causing the motor to run single-phase. If an attempt is made to start the motor, the blown fuse not being noticed, there would be no starting torque.

Consider the specific case of a six-pole, 10-hp., 1,200-r.p.m., 160-volt, three-phase motor. The motor on normal voltage, at full load, took 110 amp. in each leg. With unbalanced voltages of 161, 196, and 168, only full load could be carried, although the average of these voltages is such that it might be assumed that 25 per cent overload should be carried.

217. Induction-motor, Starting-compensator Troubles.—Sometimes a mistake is made in the connections to the compensator, so that full voltage is used at starting and the lesser voltage after throwing over the switch. Then the motor at starting takes excessive current, and, since the maximum output is in proportion to the square of the voltage, the motor capacity is much reduced when it is apparently running on the operating position. Such action, therefore, can usually be accounted for by a wrong connection in the compensator. Sometimes a motor connected to a compensator takes more current at starting than it should, under which condition a lower tap should be tried. Compensators are usually supplied with various taps, and the one should be selected which produces the least disturbance on the line, giving at the same time the desired starting torque on the motor.

When a motor, having been connected to a compensator, will not start, the cause may be entirely in the compensator. The compensator may have become open-circuited, owing to a flash within. The switch may have become deranged so that it will not close, or a connection within the compensator may have become loosened. Possibly, when a motor will not start when connected to a compensator just installed, one secondary coil of the compensator may be improperly interconnected.

218. Induction-motor, Collector-ring Troubles.—It is essential that the contact of the brushes on the collector rings be good, or the contact resistance will be so great as to slow the motor down and to cause heating of the collector itself. This effect is particularly noticeable when carbon brushes are used. The contact resistance of a carbon brush under normal operation pressure and carrying its usual density of current (40 amp. per sq. in.) is 0.04 ohm per sq. in. Thus, under normal conditions, the drop is 0.04×40, which equals 1.6 volts. If the contact is only one-quarter the surface, this drop would be 6.4 volts and might materially affect the speed of the motor. Thus, if the speed is below synchronous speed more than it should be, an investigation of the fit of the brush upon the collector may show up the trouble.

If copper brushes are used, this trouble is much less liable to occur, since the drop of the voltage due to contact resistance when running at normal density (150 amp. per sq. in.) is only one-tenth that of carbon. The same trouble may occur owing to the pigtail, which is usually used with carbon brushes, making poor contact with the carbon, which gives the same effect as a poor contact with the collector itself.

219. Improper End Play in Induction Motors.—Induction motors are so designed that the revolving parts will play endwise in the bearing, $\frac{1}{16}$ in. or so. If in setting up the machine the bearings so limit this end

action that the rotor does not lie exactly in the middle of the stator, there is a strong magnetic pull tending to center the rotor. If the bearings will not permit this centering, the thrust collars must take the extra thrust, which in an induction motor is considerable. If in addition to the magnetic thrust the belt pull is such as also to draw in the same direction, the trouble is increased. The end force may be such as to heat the bearing excessively and to cause cutting, soon rendering the motor inoperative.

In case of trouble with bearings, the end play should be tested by pushing against the shaft with a small piece of wood, placed on the shaft center. With the machine operating under normal conditions there should be no particular difficulty in pushing the shaft first one way from one side, and then the other way from the other side. If it is found that the revolving part is hugging closely against one side, the trouble can be corrected by either pressing the spider along the shaft in a direction toward which the hugging is occurring, or driving the tops of the lamination teeth in the same direction. With a wooden wedge the tops of the teeth can often be without any difficulty driven over $\frac{1}{8}$ to $\frac{3}{16}$ in. This movement will usually correct the trouble. Driving the teeth of the stator $\frac{1}{8}$ in. or so in the opposite direction to that of the end thrust will usually accomplish the same result. It is best to choose the teeth (stator or rotor) which are most easily driven over. The thin long ones move easier than do the short broad ones.

220. Oil Leakage of Induction Motors. Sometimes a bearing will permit oil to be drawn out, perhaps a very little at a time. Ultimately enough will accumulate to show on the outside or on the windings of the machine. Although a motor will run for a period with its windings wet with ordinary lubricating oil without being apparently injured, insulation soaked with oil will deteriorate and eventually fail.

One of the principal causes is a suction of the oil due to the drafts of air from the rotor, and one of the best methods of stopping the trouble, under ordinary conditions, is to cut grooves as shown in Fig. 96 at *B* and *D*. These grooves on a 50-hp. motor may be $\frac{1}{8}$ in. deep and $\frac{3}{16}$ in. wide. Each groove has three holes drilled through the bearing shell to convey the oil collected by the grooves into the oil well. These grooves are just as effective with a split as with a solid bearing. It is impossible here to go into the various causes of oil leakage. The grooves as suggested are a general remedy and cover many cases.

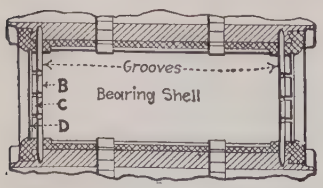


FIG. 96.—Grooves to prevent oil leakage.

221. General Summary of Synchronous-motor Troubles.—Failure of a synchronous motor to start is often due to faulty connections in the

auxiliary apparatus. These should be carefully inspected for open circuits or poor connections. An open circuit in one phase of the motor itself, or a short circuit will prevent the motor from starting. Most synchronous motors are provided with an ammeter in each phase so that the last two causes can be determined from their indications—no current in one phase in case of an open circuit, and excessive current in case of a short circuit. Either condition will usually be accompanied by a decided buzzing noise, and a short-circuited coil will often be quickly burned out. The effect of a short circuit is sometimes caused by two grounds on the machine.

Starting troubles should never be assumed until a trial has been made to start the motor light, *i.e.*, with no load except its own friction. It may be that the starting load is too great for the motor.

If the motor starts but fails to develop sufficient torque to carry its load when the field circuit has been closed, the trouble will usually be found in the field circuit. First, determine whether or not the exciter is giving its normal voltage. Assuming the exciter voltage to be correct, the trouble will probably be due to one of the following causes: (1) open circuit in the field winding or rheostat or (2) short circuit or reversal of one or more of the field spools. Open circuit can often be located by inspection or by use of the magneto.

The majority of field troubles are caused by excessive induced voltage at start or by the field circuit being broken. This excessive voltage may break down the insulation between field winding and frame or between turns on any one field spool, thus short-circuiting one or more turns, or it may even burn the field conductor off, causing an open circuit.

Causes of overheating in synchronous motors are about the same as those in a-c generators. Probably the most common cause of overheating is excessive armature current due to an attempt to make the motor carry its rated load, and at the same time compensate for a power factor lower than that for which it was designed. If the motor is not correcting low power factor but doing mechanical work only, the field current should be adjusted so that the armature current is minimum for the average load that the motor carries.

222. Difficulties in Starting Synchronous Motors.—A synchronous motor starts as an induction motor. The starting torque, as in an induction motor, is proportional to the square of the applied voltage. For example, if the voltage is halved, the starting effort is quartered. When a synchronous motor will not start, it may be because the voltage on the line has been pulled down below the value necessary for starting.

In general, at least half voltage is required to start a synchronous motor. Difficulty in starting may also be caused by an open circuit in one of the lines to the motor. Assume the motor to be three-phase. If one of the lines is open the motor becomes single-phase, and no single-phase synchronous motor, as such, is self-starting. The motor will,

therefore, not start and will soon get hot. The same condition is true of a two-phase motor if one of the phases is open-circuited.

Difficulty in starting may be due to a rather slight increase in static friction. It may be that the bearings are too tight, perhaps from cutting during the previous run. Excessive belt tension, in case the synchronous motor is belted to its load, or any cause which increases starting friction will probably give trouble. Difficulty in starting may be due to field excitation being on the motor. After excitation exceeds one-quarter normal value, the starting torque is influenced. With full field on, most synchronous motors will not start at all. The field should be short-circuited through a proper resistance during the starting period.

Usually compensators are used for starting synchronous motors. If there is a reversed phase in a compensator or if the windings of the armature of the synchronous motor are connected incorrectly, there will be little starting torque. Incorrect connection can be located by noting the unbalanced entering current. Readings to determine this unbalancing should be taken with the armature revolving slowly. The revolving can be effected by any mechanical means. While the motor is standing still, even with correct connections, the armature currents of the three phases usually differ somewhat. This is due to the position of the poles in relation to the armature, but, when the armature is revolving slowly, the currents should average up. If the rotor cannot be revolved mechanically, similar points on each phase of the armature must be found. Then when the rotor is set successively at these points the currents at each setting should be the same. Each phase, when located in a certain specific position as related to a pole, should, with right connections, take a certain specific current. With wrong connections the currents will not be the same.

223. Open Circuit in the Field of a Synchronous Motor.—If in the operation of a synchronous motor the field current breaks for any reason, the armature current will appreciably increase, causing either a shutdown or excessive heat. It becomes important therefore in synchronous motors to have the field circuit permanently established.

224. Short Circuit in an Armature Coil of a Synchronous Motor.—A short circuit in an armature coil of a synchronous motor burns it out completely, charring it down to the bare copper. When this occurs, the symptoms are so evident that there is no difficulty in identifying the trouble. Such a coil may under ordinary circumstances be cut out and operation continued. In an induction motor, the current in the short-circuited coil rises only to a certain value but heats it many times more than normal. It is not necessarily burned out immediately, and perhaps it may not be burned out at all.

225. Hunting of Synchronous Motors.—Synchronous motors served by certain primary sources of energy tend to "hunt." The periodicity of the swinging is determined by properties of the armature and the circuit. It may reach a certain magnitude and there stick, or the swing-

ing may increase until finally the motor breaks down altogether. This trouble usually occurs on long lines having considerable resistance between the source of energy and the synchronous motor. Sometimes it occurs under the most favorable conditions. Irregular rotation of a prime mover, such as a single-cylinder steam engine, is often responsible for the trouble. The usual remedy is to apply to the poles bridges of copper or brass in which currents are induced by the wavering of the armature. These currents tend to stop the motion. Different companies use different forms of bridges. When hunting or pulsating occurs and the motor is not already equipped with bridges, it is best to consult the manufacturer. In general, the weaker the field on a synchronous motor, the less the pulsation. Sometimes pulsation may be so reduced that no trouble results, simply by running with a somewhat weaker field current.

226. Improper Armature Connections in Synchronous Motors.—This trouble usually manifests itself by unbalanced entering currents and by a negligible or very low starting torque. The circuits should be traced out and the connections remade until the three entering currents for three phase, or the two entering currents for two phase, are approximately equal. These currents will not be equal even with correct connection when the armature is standing still.

227. Bearing troubles of synchronous motors are similar to those of induction motors. A difference is that with a synchronous motor the air gap between the revolving element and the poles is relatively large, so that the wearing of the bearing, which throws the armature out of center, is not so serious as with an induction motor. End play should be treated the same as with an induction motor.

228. Collector Rings and Brushes.—One of the most common sources of trouble with synchronous motors is sparking at the collector rings. Much of this trouble is due to the lack of proper care. The collector rings are one of the most important parts of the machine, and they should be frequently inspected.

Any black spots that appear on the surface of the collector should be removed by rubbing lightly with fine sandpaper the first time that the machine is shut down. It is very important that this be done because, although these spots are not serious in themselves, they will lead to pitting of the rings and the necessity of regrinding. However, no harm is done to the rings if the condition is corrected at once.

Sometimes an imprint of the brushes will be found on the surface of the collectors. This may occur on a machine which is subjected to moisture or acid fumes which will act on the surface of the ring. In case the machine is shut down for any length of time, the fumes will act upon the surface of the ring except where it is in contact with the brushes. The surface of the ring will be slightly high at this point. This causes the brush to jump slightly and arc and thus burn its imprint on the ring.

In such an installation it is good practice for the operator, when shut-

ting down the machine, to apply a little paraffin to the rings as the motor comes to a stop and while they are still warm. In general, rings give better service when the motor is run continuously than when it is shut down part of the time.

Another cause of brush imprint on the rings is a slight unbalance in the rotor, which causes a jerk or movement in the rings once every revolution. This results in jumping of the brush, with a consequent small arc, which in time burns an imprint of the brush on the ring.

Brush imprints due to fumes will occur at any point where the motor happens to stop. Imprints due to a rotor unbalance will always occur at the same place on the ring relative to the rotor.

Since there is always an electrolytic action on the surface of an iron ring, the collector operation is improved by occasionally reversing the polarity of the rings. Sometimes trouble will occur on one ring only, and by reversing the polarity every day or so the trouble will entirely disappear.

Occasionally ring trouble will arise from a ring not being of uniform hardness, so that it wears unevenly. Such a ring should be replaced. Small pinholes in the surface of a cast-iron ring will not cause trouble.

229. Bearing Troubles of Motors and Generators.—Modern generators and motors have self-oiling bearings. They should be filled to such a height that the rings will carry sufficient oil upon the shaft. If the bearings are too full, oil will be thrown out along the shaft. Watch the bearings carefully from the time the machine is first started until the bearings are warmed up; then note the oil level. The expansion of the oil due to heat and foaming raises the level considerably during that time. The oil should be renewed about once in 6 months, or oftener if it becomes dirty or causes the bearings to heat.

The bearings must be kept clean and free from dirt. They should be examined frequently to see that the oil supply is properly maintained and that the oil rings do not stick. Use only the best quality of oil. New oil should be run through a strainer if it appears to contain any foreign substances. If the oil is used a second time it should first be filtered and, if warm, allowed to cool. If a bearing becomes hot, first feed heavy lubricant copiously, loosen the nuts on the bearing cap, and then, if the machine is belt connected, slacken the belt. If no relief is afforded by these means, shut down, keeping the machine running slowly until the shaft is cool, in order that the bearing may not "freeze." Renew the oil supply before starting again. A new machine should always be run at a slow speed for an hour or so in order to see that it operates properly. The bearings should be inspected at regular intervals to ensure that they always remain in good condition. The higher the speed, the more care should be taken in this regard.

A warm bearing or "hot box" is probably due to one of the following causes: (1) excessive belt tension, (2) failure of the oil rings to revolve

with the shaft, (3) rough bearing surface, and (4) improper lining up of bearings or fitting of the journal boxes.

CARE OF MOTORS[1]

230. Modern methods of design and construction have made the electric motor one of the least complicated and most dependable forms of machinery in existence and have thereby made the matter of its maintenance one of comparative simplicity. This statement should not, however, be taken to mean that proper maintenance is not important; on the contrary, it must be given careful consideration if the best performance and longest life are to be expected from the motor. The two major features, from the standpoint of their effect upon the general performance of the motor, are those of proper lubrication and the care given to the insulation, because they concern the most vital, and probably the most vulnerable, parts of the machine. The former will be discussed here only with regard to its relation to the maintenance of the insulation.

231. Lubrication.—The designs of bearings and bearing housings of motors have been wonderfully improved in the last few years. The point has now been reached where the bearings of modern motors, whether sleeve, ball, or roller, require only very infrequent attention.

This advance in the art is not yet fully appreciated, for, although there may have been some necessity for more frequent attention in the case of older designs with housings less tight than on modern machines, oiling and greasing of new motors is quite often entrusted to uninformed and careless attendants, with the result that oil or grease is copiously and frequently applied to the outside as well as the inside of bearing housings. Some of the excess lubricant is carried into the machine and lodges on the windings, where it catches dirt and thereby hastens the ultimate failure of the insulation.

The modern designs provide for a plentiful supply of oil or grease being held in dusttight and oiltight housings. If the proper amount of a suitable lubricant is applied before starting, there should be no need to refill the housings for several months, even in dusty places. Infrequent though periodic and reasonable attention to modern bearings of any type will tend toward longer life of both bearings and insulation.

232. Care of Insulation.—Motors should be stored in a dry, clean place until ready for installation. Heat should be supplied, especially for larger high-voltage machines, to protect against alternate freezing and thawing. This is equally applicable to spare coils.

Motors that have been long in transit in moist atmosphere or have been idle for an extended period without heat to prevent the accumulation of moisture should be thoroughly dried out before being placed in service. Machines may also become wet by accident, or they may "sweat" as a result of a difference in their temperature and that of the surrounding air,

[1] Courtesy of General Electric Company.

just as cold water pipes "sweat" in a warm, humid atmosphere. This condition is, of course, very injurious and should be prevented, particularly in the case of large or important motors, by keeping them slightly warm at all times. Current at a low voltage can be passed through the windings, electric heaters can be used, or even steam pipes can be utilized for protective purposes. In the case of extended idle periods, tarpaulins may be stretched over the motor and a small heater put inside to maintain the proper temperature.

233. Drying Out.—If a motor has become wet from any cause whatever, it should be dried out thoroughly before being operated again. The most effective method is to pass current through the windings, using a voltage low enough to be safe for the winding in its moist condition. For 2,200-volt motors, 220 volts is usually satisfactory for circulating this drying-out current. Thermometers should be placed on the windings to see that they are being heated uniformly. Temperatures should not exceed 90°C. (Class A insulation). Applying the heat internally in this manner drives out all moisture and is particularly effective on high-voltage motors, where the insulation is comparatively thick.

Heat may be applied externally by placing heating units around or in the machine, covering the whole with canvas or other covering and leaving a vent at the top to permit the escape of moisture. In doing this it is essential that there be a circulation of warm air over all the surfaces to be dried. The air should be allowed to escape as soon as it has absorbed moisture. Therefore, the heaters should be so placed and baffles so arranged as to get a natural draft; or small fans may be used to force circulation. Twelve-inch fans set to blow air across the fronts of "glow heaters" and then into the lower part of a machine from opposite sides, and so on up around the windings and out the top, will produce excellent results. The temperature of the winding should not be allowed to exceed 100°C. for Class A insulated motors. Smaller machines may conveniently be placed in ovens, the same temperature limits being observed.

233A. Insulation-resistance Tests.—The time required for complete drying out depends considerably on the size and voltage of the motor. Insulation-resistance measurements should be taken at intervals of 4 or 5 hr. until a fairly constant value is reached. This value should at least equal the recommended American Institute of Electrical Engineers Standard, which is

$$\text{Megohms} = \frac{\text{voltage}}{\text{kva.} + 1{,}000} \tag{9}$$

The insulation resistance of dry motors in good condition is considerably higher than this value.

The more convenient way to measure this resistance is through the use of a megohmmeter, although if a 500-volt, d-c source is available readings

can be taken with a voltmeter. The ungrounded side of the system should be connected to all the motor terminals through the voltmeter, the opposite or grounded side being connected directly to the motor frame. The insulation resistance is found by the method of Sec. **171** of Div. 1.

In using the voltmeter method, the connection to the frame should always be made through a fuse of not more than 10 amp. in size. The circuit should be tested, and the side showing a complete or partial ground then connected to the frame through the fuse.

Obviously, the insulation resistance varies over a wide range, depending upon moisture, temperature, cleanliness, etc., but it is a good indication of the general condition of the insulation and its ability to stand the operating voltage. Such readings should be taken before a high-potential test, to determine whether the insulation is ready for such a test, and afterwards to make sure that the high potential has not injured the insulation.

233B. High-potential Tests.—High-potential tests should be made after drying out, or after repairs, to determine the dielectric strength of the insulation. New windings should successfully stand a high-potential test of twice normal voltage plus 1,000. There is some disagreement as to the proper value to use for motors that have been in operation for some time, but it is reasonable to assume that, after thorough cleaning and drying, the winding of a used motor should stand 150 per cent of normal voltage for 1 min.

Small high-potential testing sets are available for such work and are of such capacity that very little damage will result from a breakdown during the test.

233C. Periodic Inspection.—A systematic and periodic inspection of motors is necessary to ensure best operation. Of course, some machines are installed where conditions are ideal, where dust, dirt, and moisture are not present to an appreciable degree; but most motors are located where some sort of dirt accumulates in the windings, lowering the insulation resistance and cutting down creepage distance. Steel-mill dusts are usually highly conductive, if not abrasive, and lessen creepage distances. Other dusts are highly abrasive and actually cut the insulation in being carried through by the ventilating air. Fine cast-iron dust quickly penetrates most insulating materials. Hence the desirability of cleaning the motors periodically. If conditions are extremely severe, open motors might require a certain amount of cleaning each day. For less severe conditions, weekly inspection and partial cleaning are desirable. Most machines require a complete overhauling and thorough cleaning about once a year.

For the weekly cleaning, the motor should be blown out, using moderate-pressure, dry, compressed air (or about 25 to 30 lb. per sq. in. pressure). Where conducting and abrasive dusts are present, even lower pressure may be necessary, and suction is to be preferred, as damage can

easily be caused by blowing the dust and metal chips into the insulation. On most d-c motors and large a-c motors the windings are usually fairly accessible, and the air can be properly directed to prevent such damage.

On the larger a-c machines the air ducts should be blown out so that the ventilating air can pass through as intended.

On large machines, insulation-resistance readings should be taken in the manner heretofore indicated. As long as the readings are consistent, the condition of the insulation would ordinarily be considered good. Low readings would indicate increased current leakage to ground, or to other conductors, owing to one of perhaps several causes, such as deteriorated insulation, moisture, dirty or corroded terminals, etc.

234. Cleaning.—About once a year, or oftener if conditions warrant, motors should be overhauled. Smaller motors, the windings of which are not particularly accessible, should be taken apart.

First, the heavy dirt and grease should be removed with a heavy, stiff brush, wooden or fiber scrapers, and cloths. Rifle-cleaning bristle brushes can be used in the air ducts. Dry dust and dirt may be blown off, using dry compressed air at moderate pressure, for example, 25- to 50-lb. pressure at the point of application, taking care to blow the dirt out from the winding. As stated before, if the dirt and dust are metallic, conducting, or abrasive, air pressure may drive the material into the insulation and damage it. Hence, for such conditions, pressure is not so satisfactory as a suction system. If compressed air at low pressure is used, care must be taken to direct it properly so that the dust will not cause damage and will not be pocketed in the various corners.

Grease, oil, and sticky dirt are easily removed by applying cleaning liquids like carbon tetrachloride (Pyrene, Carbona), gasoline, or naphtha. All these liquids evaporate quickly and, if not applied too generously, will not soak or injure the insulation. Carbon tetrachloride is best and is recommended because it is noninflammable.

In case one of the other liquids must be used, it should be applied out-of-doors or in a well-ventilated room. It must be remembered that gasoline or naphtha vapor is heavier than air and will flow into pits, basements, etc., and may remain there for hours or even days. The casual smoker or a spark from a hammer or chisel or even from a shoe nail may cause a serious explosion. Therefore, proper ventilation of the room is essential and may require specially piped ventilating fans. In using carbon tetrachloride the explosion hazard is obviated, but some ventilation is required to remove the vapor, which might affect the safety and comfort of the workmen.

There are several good methods of applying the cleansing liquid. A cloth, saturated in the liquid, may be used to wipe the coils. A paint brush, dipped in carbon tetrachloride, is handy to get into corners and crevices, and between small coils. Care should be taken not to soak the insulation, as would be the case if coils or small machines were dipped into the liquid.

Probably the best method of applying the liquid is to spray it on. A spray gun, paint-spraying appliance, or an ordinary blowtorch is often used with good results, although the latter device is likely to give a heavier spray than desirable.

An atomizer will give excellent results, using a pressure of about 80 lb. if the insulation is in good condition, or 40 to 50 lb. if the insulation is old. The atomizer should be held not more than 5 or 6 in. away from the coils.

Although the insulation will dry quickly at ordinary room temperature after such cleaning methods, it is highly desirable to heat it to drive off all moisture before applying varnish. This heating or drying-out process has already been discussed and therefore need only be mentioned here.

If the motor can be spared from service long enough, the insulation should be dried out by heating to from 90 to 100°C. While the motor is warm, a high-grade insulating varnish should be applied. For severe acid, alkali, or moisture conditions, a black plastic baking varnish is best, while for conditions where oil or dusts are present a clear or yellow varnish should be used.

The varnish may be sprayed or brushed on. For small stators or rotors, it is best to dip the windings into the varnish, cleaning off the adjacent metal parts afterwards by using a solvent of the varnish. After applying the varnish, the best results are obtained by baking for 6 to 7 hr. at about 100°C. Experience with particular conditions of operation, or the condition of the insulation, may indicate the desirability of applying a second coat of the same varnish, followed again by 6 to 7 hr. of baking at 100°C.

If the machine must be put back in service quickly, or if facilities are not available for baking, fairly good results will be obtained by applying one of the quick-drying black or clear varnishes which dry in a few hours at ordinary room temperatures.

Insulation-resistance readings should be taken, as explained previously, to determine whether the winding is in satisfactory condition for applying a high-potential test. After this test, it is good practice to run the motor without load for a short time, to make certain that everything has been connected, assembled, and adjusted properly.

CONTROL EQUIPMENT FOR MOTORS

235. Electric Controller Terminology. Acid-resistant Apparatus.—Apparatus so constructed that it will not be readily injured by acid fumes.

Constant-torque Resistor (Machine Duty).[1]—A resistor for use in the armature or rotor circuit of a motor in which the current remains practically constant throughout the entire speed range (American Standard). This means that the horsepower output of the motor decreases directly

[1] The two types of regulating resistors are laid out very differently in ohmic value and current-carrying capacity and cannot be used interchangeably. All orders for such resistors should specify whether they are for machine or fan duty.

with the speed, as in the case of a motor driving a plunger pump. Here, the work done by the motor at one-half speed is one-half that done at full speed. The term "machine duty" is not meant to imply that any motor driving a machine should have a machine-duty resistor.

Continuous Duty.—A requirement of service that demands operation at substantially constant load for an unlimited period (American Standard).

Dripproof Apparatus.—Apparatus so constructed or protected that its successful operation is not interfered with when subjected to falling moisture or dirt (American Standard).

Driptight Apparatus.—Apparatus so protected as to exclude falling moisture or dirt. Driptight apparatus may be semienclosed apparatus if it is provided with suitable protection integral with the apparatus or so enclosed as to exclude effectively falling solid or liquid material (American Standard).

Drum Controller.—A drum controller is a controller that utilizes a drum switch as the main switching element (American Standard).

Drum Switch.—A drum switch is a switch having electric connecting parts in the form of fingers, held by spring pressure against contact segments or surfaces on the periphery of a rotating cylinder or sector (American Standard).

Dustproof Apparatus.—Apparatus so constructed or protected that the accumulation of dust will not interfere with its successful operation (American Standard).

Dusttight Apparatus.—Apparatus so constructed that dust will not enter the enclosing case (American Standard).

Duty of a Controller.—The specific function or functions that are designed to be accomplished with respect to the operation of the motor, such as starting, speed control, reversing, and stopping and, in addition, the frequency and length of time of operation (American Standard).

Electric Controller.—A device, or group of devices, which serves to govern in some predetermined manner the electric power delivered to the apparatus to which it is connected (American Standard).

NOTE.—The term controller therefore is properly applied to dial-type starters, rheostats, contactor panels, etc. It is not limited to controllers of the drum type.

Fan-duty Resistor.[1]—A resistor for use in the armature or rotor circuit of a motor in which the current is approximately proportional to the speed of the motor (American Standard). For example, a fan driven at one-half its normal speed requires less than one-half as much torque as it would require running at its normal speed, and the work done by the motor will be less than one-quarter as much as that done at normal speed.

[1] The two types of regulating resistors are laid out very differently in ohmic value and current-carrying capacity and cannot be used interchangeably. All orders for such resistors should specify whether they are for machine or fan duty.

Full-magnetic Controller.—A controller having all its basic functions[1] performed by electromagnets (American Standard).

Example.—One which performs all its operations after the closure of the master switch, such as a magnetic control panel with a "start-stop," push-button station.

Fume-resistant Apparatus.—Apparatus so constructed that it will not be readily injured by the specified fumes (American Standard).

Gasproof Apparatus.—Apparatus so constructed or protected that the specified gas will not interfere with its successful operation (American Standard).

Gastight Apparatus.—Apparatus so constructed that the specified gas will not enter the enclosing case under specified conditions of pressure (American Standard).

Isolating Switch.—An isolating switch is a switch intended for isolating an electric circuit from the source of power. It is intended to be operated only when the circuit has been opened by some other means (American Standard).

Machine Duty.—See Constant-torque Resistor.

Magnetic Contactor.—A contactor actuated by electromagnetic means (American Standard).

Example.—Shunt contactor.

Manual Controller.—A controller having all its basic functions performed by hand (American Standard).

Example.—A hand-starting rheostat or drum-type controller.

Master Switch.—A device which serves to govern the operation of contactors and auxiliary devices of an electric controller (American Standard).

Example.—A master switch may be automatic, such as a float switch or pressure regulator, or it may be manually operated, such as a drum, push-button, or knife switch.

Moisture-resistant Apparatus.—Apparatus so constructed or treated that it will not be readily injured by a moist atmosphere. (Such apparatus shall be capable of operating in a very humid atmosphere, such as found in mines, evaporating rooms, etc.) (American Standard.)

Open-phase Relay.—A relay that functions by reason of the opening of one phase of a polyphase circuit (American Standard).

Overload Protection.—The effect of a device operative on excessive current, but not necessarily on short circuit, to cause and maintain the interruption of current flow to the device governed. When it is a function of a controller for a motor, device employed shall provide for inter-

[1] By "basic function" is usually meant acceleration, retardation, line closing, and reversing (American Standard).

rupting any operating overloads[1] but shall not be required to interrupt short circuits (American Standard).

Overload Relay.—An overcurrent relay in the circuit of a motor that functions at a predetermined value of the current to cause the disconnection of the motor from the line (American Standard).

Periodic Duty.—A requirement of service that demands operation for alternate periods of load and rest in which the load conditions are well defined and recurrent as to magnitude, duration, and character (American Standard).

Phase-failure Protection.—The effect of a device, operative on the failure of power in one wire of a polyphase circuit, to cause and maintain the interruption of power on the circuit (American Standard).

Phase-reversal Protection.—The effect of a device, operative on the reversal of the phase rotation on a polyphase circuit, to cause and maintain the interruption of power in all the circuit (American Standard).

Relay.—A device that is operative by a variation in the conditions of one electric circuit to effect the operation of other devices in the same or another electric circuit (American Standard).

Semimagnetic Controller.—A controller having part of its basic functions[2] performed by electromagnets and part by other means (American Standard).

Service of a Controller.—The specific application in which the controller is to be used, as for example:

1. General purpose, which covers the occasional starting of motors.
2. Crane and hoist.
3. Elevator.
4. Machine tool, etc. (American Standard.)

Sleetproof Apparatus.—Apparatus so constructed or protected that the accumulation of sleet will not interfere with its successful operation (American Standard).

Splashproof Apparatus.—Apparatus so constructed and protected that external splashing will not interfere with its successful operation (American Standard).

Submersible Apparatus.—Apparatus so constructed that it will operate successfully when submerged in water under specified conditions of pressure and time (American Standard).

Temperature Relay.—A relay that functions at a predetermined temperature in the apparatus protected (American Standard).

Undervoltage Protection.—The effect of a device, operative on the reduction or failure of voltage, to cause and maintain the interruption of power to the main circuit (American Standard).

[1] By "operating loads" is meant a current not in excess of six times the rated full-load current for a-c motors, or four times the full-load current for d-c motors (American Standard).

[2] By "basic function" is usually meant acceleration, retardation, line closing, and reversing (American Standard).

Undervoltage Release.—The effect of a device, operative on the reduction or failure of voltage, to cause the interruption of power to the main circuit, but not to prevent the reestablishment of the main circuit on return of voltage (American Standard).

Watertight Apparatus.—Apparatus so constructed that a stream of water from a hose (not less than 1 in. in diameter), under a head of about 35 ft. and from a distance of about 10 ft., can be played on the apparatus for several minutes without leakage (American Standard).

Weatherproof Apparatus.—Apparatus so constructed or protected that exposure to the weather will not interfere with its successful operation (American Standard).

236. Enclosure of Controllers.—Except where the control equipment is mounted on switchboard panels under the control of experienced operators, the control equipment of motors should be enclosed in a metal case. Different types of enclosures, such as general purpose, dripproof, watertight, etc., are available to meet the requirements of any surrounding conditions. For definitions of these terms, refer to Sec. **235.** Most general-purpose controllers are enclosed in a sheet-metal case. If a controller must be placed in a hazardous location in explosive atmospheres the advice of the experts of the control manufacturers should be consulted. The standard types of nonventilated enclosures furnished by one manufacturer are given in Sec. **237.** They are typical of the types available.

237. Classification of Standard Types of Nonventilated Enclosures for Electric Controllers (General Electric Company).

Type I. General Purpose.—A sheet-metal case designed to meet such general specifications of the Underwriters' Laboratories for enclosures as may be in effect from time to time, and primarily to protect against accidental contact.

Type I case is suitable for general-purpose application, indoors, and where atmospheric conditions are normal. It serves as protection against dust and against light indirect splashing but is not dusttight.

Felt gaskets can be provided as an option.

Type II. Dripright.—A sheet-metal case similar to Type I, with the addition of drip shields or their equivalent.

Type II case is suitable for application where condensation may be severe, as in cooling rooms and laundries. It meets the requirements of N.E.M.A. definitions IC50-30 and IC50-33.

Type III. Weather-resisting.—A case of cast construction, or of sheet metal of suitable rigidity, with proper protection against weather hazards, as rain and sleet.

Type III case is suitable for outdoor application, as on docks, canal locks, and construction work and also for application in subways and tunnels. It meets the requirements of N.E.M.A. definitions IC50-35, IC50-45, IC50-48, and IC50-56.

TYPE IV. WATERTIGHT.—A case of cast construction, or of sheet metal of suitable rigidity, designed to meet the hose test described in N.E.M.A. definition IC50-43.

Type IV case is suitable for application outdoors, on ship docks, and in dairies, breweries, and similar locations.

TYPE V. DUSTTIGHT.—A case of cast construction, or of sheet metal of suitable rigidity, and provided with gaskets or the equivalent to exclude dust. It meets such requirements of N.E.M.A. definition IC50-28, and of the National Electrical Code for Class III and Class IV locations, as may be in effect from time to time.

Type V case is suitable for application in steel mills, cement mills, and other locations where it is desirable to exclude dust.

TYPE VI. SUBMERSIBLE.—A case designed to meet the requirements of N.E.M.A. definition IC50-50.

Type VI case is suitable for application where it may be subject to submersion in water, as in quarries, mines, and manholes. The design will depend on the specified conditions of pressure and time.

Wiping joints for cable connection can be provided as an option.

TYPE VII. HAZARDOUS LOCATIONS: CLASS I, AIR-BREAK.—A case designed to meet the application requirements of the National Electrical Code for Class I, Group D, hazardous locations that may be in effect from time to time, and in accordance with the Underwriters' Laboratories, specifications that may be in effect from time to time.

TYPE VIII. HAZARDOUS LOCATIONS: CLASS I, OIL-IMMERSED.—A case designed for the application requirements of the National Electrical Code for Class I, Group D, hazardous locations that may be in effect from time to time, and in accordance with the Underwriters' Laboratories' specifications that may be in effect from time to time; the apparatus being immersed in oil.

TYPE IX. HAZARDOUS LOCATIONS: CLASS II.—A case designed for the application requirements of the National Electrical Code for Class II hazardous locations that may be in effect from time to time, and in accordance with the Underwriters' Laboratories' specifications.

TYPE X. BUREAU OF MINES.—A case designed to meet the requirements of the U.S. Bureau of Mines.

Type X case is for application in coal mines.

NOTE 1.—When an enclosure is required to meet N.E.M.A. definition IC50-53 (gasproof) or IC50-55 (gastight), the selection of a suitable type will depend on whether protection is desired against corrosion or against explosion and fire.

NOTE 2.—When an enclosure is required to meet N.E.M.A. definition IC50-60 (acid resistant), or IC50-63 (fume resistant), the design will depend on the condition of exposure.

238. Electric controllers are classified according to the method of performing the necessary operations, as follows:

1. Manual.
2. Magnetic.
   a. Full magnetic with automatic master switch.
   b. Full magnetic with manual master switch.
   c. Semimagnetic.

In a manual controller all the basic operations, such as closing of switches and movement of rheostat handles, etc., are performed by hand.

In a magnetic controller the basic functions of closing of switches or movement of rheostat handles are performed by magnetic contactors (see Sec. **235**). A full-magnetic controller is one which automatically performs all its operations in the proper sequence after the closure of a master switch. The master switch for a full-magnetic controller, such as a float switch, a pressure switch or regulator, or a time switch, is frequently automatically operated. In other cases, the master switch, such as a push-button, drum, or knife switch, is manually operated. A semimagnetic controller operates with a combination of manual and magnetic performance. In some cases, part of the basic operations are performed by hand and the rest by means of magnetic contactors. In other types of semimagnetic controllers, all the basic operations are performed with magnetic contactors, but the time and sequence of the operation of the contactors is controlled by hand.

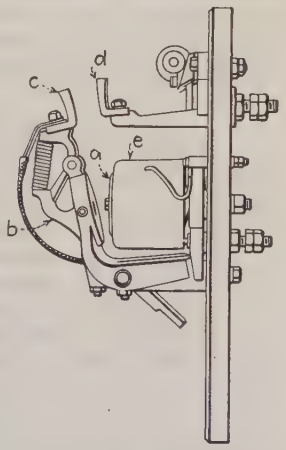


FIG. 97.—Magnetic contactor. (*Electric Controller & Manufacturing Co.*)

239. A magnetic contactor is a switch operated by an electromagnet. One form of magnetic contactor is shown in Fig. 97, which illustrates the basic parts. It consists of a stationary electric magnet, as at *a* in Fig. 97, a movable iron armature *b*, on which is mounted an electrical contact *c* and a stationary electrical contact *d*. When there is no current flowing through the operating coil *e* of the electrical magnet *a*, the armature is held away from the magnet by means of gravitational force or a spring. Under this condition the contacts *c* and *d* are open. When the operating coil is energized, the magnet attracts the armature and closes the electrical contacts *c* and *d*.

Magnetic contactors may be of the shunt or series type, depending upon the connection of the operating coil. In the shunt contactor the operating coil is connected across the terminals of the circuit or portion of the circuit that the contactor is controlling. In some cases the operating coil of a shunt contactor might be connected to a separate source of

supply from the circuit controlled by the contactor. A series contactor has its operating coil connected in series with the circuit which is controlled by the contactor.

240. Series contactors for motor-control application are constructed so that the contactor will not close until the current of the circuit has dropped below a definite value. They are made in two general forms: single coil and two coil. The single-coil type is referred to simply as a series contactor, while the two-coil type is called a series lockout contactor. Both of the types, however, possess the lockout feature of the contactor, *i.e.*, they are held open until the current has dropped to some definite value.

The general principle of operation of the single-coil type can be understood from a study of Fig. 98. The current passing through the operating coil produces an m.m.f. which acts upon two magnetic paths. One path is through the core of the coil, a section of restricted area *A*, the armature, and main air gap back to the core of the coil. The other path is through the core of the coil, adjustable air gap, tail of armature *B*, armature, and main air gap back to the core of the coil. When no current is passing through the coil, the armature is in the open position. When a large current is passing through the operating coil, the m.m.f. is so strong that the part *A* of restricted area becomes saturated so that the flux through this part cannot exceed a certain amount. The magnetic flux through the adjustable air gap and part *B* will vary with the current through the operating coil, and this path will not become saturated. Any flux passing across the adjustable air gap produces an attracting force on the tail of the armature *B* which tends to hold the armature open against the closing force exerted between the core and the main part of the armature. As the current reduces in value, the flux across the adjustable air gap reduces and thus reduces the holding-out force on tail *B*. After the current has reduced to a certain value, which depends upon the adjustment of the adjustable air gap, the holding-out force on tail *B* is not sufficient to overcome the closing force exerted by the core upon the main part of the armature, and the contactor closes.

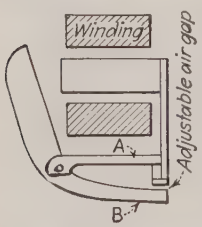


FIG. 98.—Series contactor operating magnet.

In the two-coil type or series contactor (Fig. 99), two coils are connected in series with each other and the circuit to be controlled. The armature is pivoted so that one coil, the larger of the two, acts upon one side of the armature, exerting a force tending to close the contactor. The smaller coil acts upon the other side of the armature and exerts a force tending to hold the contactor open. The areas of the magnetic circuits are so designed that the force tending to close the contactor remains practically constant regardless of the value of current, while the force

tending to hold the contactor open varies with the current. Therefore, after the current has decreased to a certain value, the holding-out force is not sufficient to overcome the closing force, and the contactor closes. The air gap of the locking-out circuit can be adjusted so that the current above which the contactor holds open can be adjusted over a wide range.

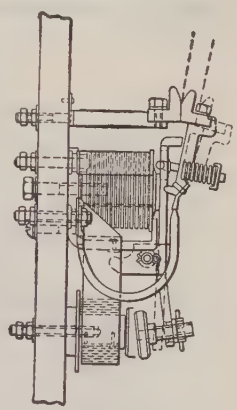


Fig. 99.—Magnetic lockout contactor.

241. Overload Protective Devices.—Most motor controllers have incorporated with them as an integral part of the controller some device for protecting the motor against overloads that will be harmful to the motor. These overload protective devices are made in many different types and forms of construction, depending upon the ideas of the different manufacturers of control equipment. Those made by reliable manufacturers have the approval of the National Board of Fire Underwriters. Before purchasing control equipment, care should be taken to make sure that the equipment has been passed by this Board. All the following types of overload protective devices are used in motor-control equipment.

1. Standard fuses.
2. Super-time-lag fuses.
3. Thermal cutouts.
4. Thermal release devices.
5. Thermal relays.
6. Magnetic overload relays.

For a description of these devices see Div. 4.

For selection of overload protective devices with respect to both size and type refer to Secs. **436, 437, 438,** and **439.**

242. Undervoltage Devices.—Most motor starters are provided with either an undervoltage protective device or an undervoltage release device.

An undervoltage protective device is one which opens the supply circuit to the motor upon failure or reduction of voltage and which maintains the circuit open until it is again closed by the operator.

An undervoltage release device is one which operates on a reduction or failure of voltage, thereby opening the main circuit, but it does not prevent the automatic reclosing of the main circuit upon the return of normal voltage. It is applied in conjunction with some automatic starters. In certain applications, such as fans, blowers, and pumps, an automatic starter provided with an undervoltage release may be advantageously used. Its operation on a reduction or failure of voltage will stop the motor. Then the reestablishment of voltage causes the automatic

starter to restart the motor, thus minimizing the shutdown period. An undervoltage release should not be employed in applications where an unexpected return of power would endanger an operator.

243. The methods of controlling the acceleration of motors with the type of power system on which they may be used are given below:

Methods	Applicable to
A. No control (across-the-line starting)	A-c and small d-c motors
B. Manual	A-c and d-c
C. Automatic:	
1. Time:	
a. Escapement	A-c and d-c
b. Solenoid with action retarded by an adjustable dashpot	D-c
c. Mercury timer	A-c and d-c
d. Synchronous-motor timer relay	A-c
e. Inductive time limit	A-c and d-c
f. Condenser charge (neotime)	A-c or d-c
2. Current	A-c and d-c
3. Counter-e.m.f.	D-c
4. Time current:	
a. Magnetic relay	D-c
b. Condenser charge (neotime current)	A-c
5. Frequency	A-c

The simplest method is of course no control, in which the motor is thrown directly across the line by means of a manual or magnetic switch. The speed of acceleration of the motor and the magnitude and duration of the starting current depend solely upon the characteristics of the motor and its connected load.

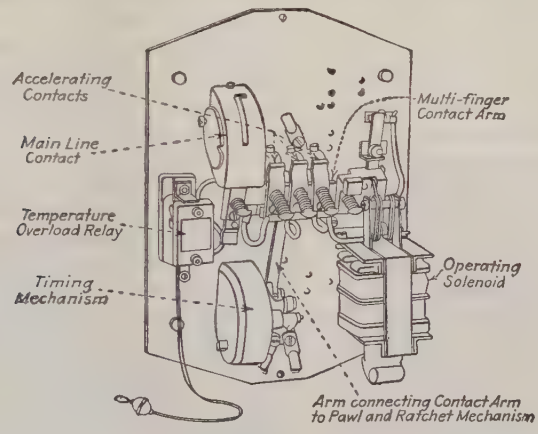
With manual control of the acceleration the speed of acceleration depends upon the judgment of the operator. Manual control of acceleration can be obtained through the use of manual controllers or semimagnetic controllers. In the semimagnetic controllers of this type the time and sequence of closing of the magnetic contactors is controlled by means of a manually operated master switch.

With automatic acceleration the only part of the starting operation that may be dependent upon the operator is the initiation of the sequence of events (such as pushing a start button). When this is done, the resulting sequence of operations is automatically performed and controlled by means of contactors alone or contactors controlled by relays.

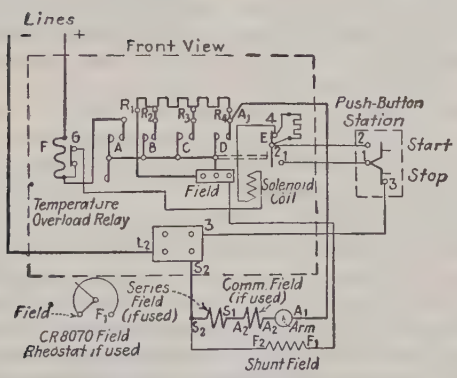
244. In time-limit acceleration the closing of the respective contactor contacts is controlled by a timing device so that the starting resistance is shorted out of the circuit, or connections to the autotransformer are changed, in a certain definite time. Most modern automatic starters are of the time-limit type. They are used for all general-purpose applications. The other types of automatic acceleration are used for special applications where they have advantages over the time-limit type. The

timing of the closing of the respective contactors for time-limit acceleration may be accomplished in several ways as listed in Sec. **243.**

245. A general understanding of time-limit control of acceleration by a pawl-and-ratchet escapement mechanism can be obtained from a study



Starter Removed from Case



Wiring Diagram

FIG. 100.—Time-limit starter for direct-current motor. (*General Electric Co.*)

of the typical starter of this type for a d-c motor such as is shown in Fig. 100. The four contacts *A*, *B*, *C*, and *D* are all connected by spring connections to the same arm, which is operated by the solenoid coil. Pushing the start button closes a circuit from the positive side of the line through the solenoid coil to 2, through the start and stop push buttons to 3, and back to the negative side of the line. The solenoid now being

energized exerts a torque upon the multifinger contact arm and closes the main contact. This connects the armature of the motor to the line in series with the total starting resistance. The closing of the main-line contact also connects the shunt field of the motor directly across the line. As soon as the solenoid is energized and closes the main contact, the accelerating contactors B, C, and D also try to close, since all the contact fingers are connected to the same arm. The arm is prevented from moving far enough to close the accelerating contacts by means of the timing mechanism. The stationary contacts are so arranged that it requires a greater movement of the contact arm to close each consecutive contact. The movement of the contact arm is controlled by the timing mechanism. The contact arm is connected by a pawl-and-ratchet mechanism to the timing device. The torque exerted by the solenoid attempting to close the accelerating contacts is transmitted through the pawl-and-ratchet mechanism to the gears of the timing device, causing them to rotate. The escapement of the timing device permits the gears to rotate only at a certain rate. At a certain definite time after the closing of the main-line contact A, the timing mechanism has allowed its gears to rotate sufficiently so that the pawl and ratchet will allow contact finger B to close. The closing of contact finger B shorts out the section R_1R_2 of the starting resistance. As the gears of the timing device continue to rotate under the torque exerted upon them by the solenoid through the contact arm and pawl-and-ratchet mechanism, the contacts C and D will be allowed to close with the proper time interval between each closing. When contact D closes, the motor will be connected directly across the line.

At the same time that the contact arm closes the main-line contact, it acts upon the auxiliary switch E, opening contact 4–2 and closing contact 2–1. A closed circuit is thus maintained through the solenoid coil when the start button is released.

The parts F and G are, respectively, the heater element and contacts of a temperature overload relay. In case of an overload the heating of the element F opens the contact G. The opening of contact G opens the circuit of the solenoid coil so that the contact arm returns to the "off" position, disconnecting the motor from the line. This starter provides undervoltage protection. If the voltage drops to too low a value, the solenoid coil is not energized sufficiently to hold the contactor arm closed. The motor will not start again until the operator pushes the start button.

The timing mechanism consists of a simple pendulum arrangement similar to the escapement on a clock. It can be adjusted to give a total accelerating period of from 2 to 8 sec.

Escapement time relays are frequently used in controllers for control of the acceleration contactors. The relay is similar in operation to the multifinger contactor of the previously described starter. The relay, of course, has much smaller contact fingers since the contacts have only to

carry much smaller values of currents. In the operation of such a relay the operating coil of the relay would be energized after the main-line motor contactor closes. The relay will then automatically close its successive contacts with a definite time delay between the closing of the respective contacts. As each contact is closed it will energize the operating coil of an accelerating contact.

246. With time-limit acceleration provided by means of a solenoid with action retarded by an adjustable dashpot, the operation is similar to that of the escapement type except that the motion of the contactor operating arm is controlled by means of an oil dashpot attached to the

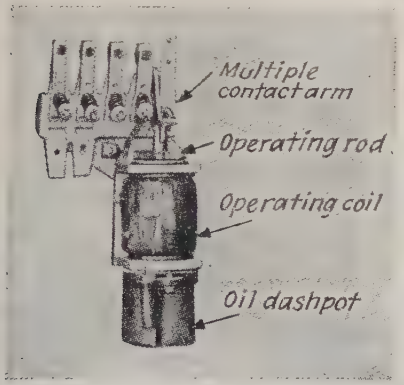


FIG. 101.—Time-limit acceleration mechanism of the multiple-finger oil-dashpot type.

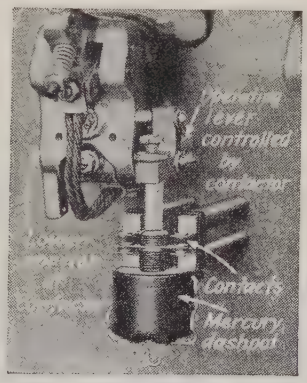


FIG. 102.—Mercury dashpot timer. (*Electric Controller & Manufacturing Co.*)

lower part of the operating rod of the solenoid. A typical assembly of a multifinger contact arm operated by a solenoid and retarding dashpot are shown in Fig. 101. The time of the accelerating period may be adjusted by a screw on the outside of the dashpot which adjusts the oil escapement orifice.

247. The mercury dashpot timer consists of a rubber vacuum cup, operating in a molded bakelite pot containing mercury, and an operating plunger which actuates the contacts. The plunger is actuated by means of a lever attached to the arm of a contactor. When the contactor is open (Fig. 102) the rubber vacuum cup at the lower end of the plunger is pressed down against the hollow of the mercury pot. When the contactor closes, removing the weight of the contactor arm from the relay, a spring tends to pull the vacuum cup from the bottom of the mercury pot, but operation is prevented until mercury flows through an orifice in the plunger to fill the vacuum cup. The plunger at its upper end carries a contact bridge which opens one set of contacts and closes another set as the relay operates. For normal acceleration duty, only the normally

open contacts are required to close the succeeding acceleration contactor.

The time interval provided by the relay in adjustable from ½ to 3 sec. Adjustment is obtained by turning the adjusting screw, which determines the amount that the rubber cup is flattened against the bottom of the mercury pot.

The principle of controlling acceleration by means of a mercury timer is shown in Fig. 103. All contactors except the last acceleration contactor are equipped with a mercury timer. When the start button is pressed, current flows from $L1$, through stop and start buttons to 10, through the operating coil ③, through contacts $\frac{0.L.}{o\,|\,o}$ and back to $L2$. This energizes the operating coil ③ of the main-line contactor $\overset{3}{\dashv\vdash}$. Contactor $\overset{3}{\dashv\vdash}$ closes, connecting the motor across the line in series with all the starting resistance. When contactor $\overset{3}{\dashv\vdash}$ closes, it closes its auxiliary contacts $\frac{3}{o\,|\,o}$, which provides a means of energizing the operating coils of the contactors when the start button is released. The closing of contactor 3 causes the mercury timer $3M$ to start to function. After a certain definite time required for the mercury to pass through the orifice of the plunger, mercury timer $3M$ closes its contacts $\overset{3M}{\dashv\vdash}$. This energizes the operating coil ④ of accelerating contactor 4, which closes its contacts $\overset{4}{\dashv\vdash}$. This shorts the resistance $R_7 - R_8$. The closing of contactor 4 causes the mercury timer $4M$, attached to it, to start to function. After a certain definite time this timer closes its contacts $\overset{4M}{\dashv\vdash}$, energizing the operating coil ⑤ of accelerating contactor 5. Contactor 5 operates, closing its contacts $\overset{5}{\dashv\vdash}$ and shorting out resistance $R_6 - R_7$. The motor is now connected directly across the line.

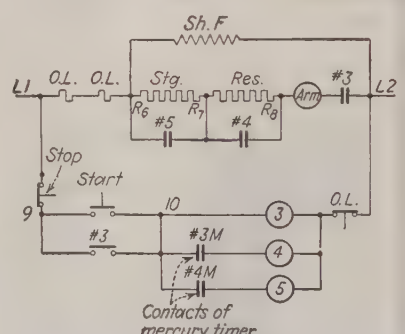


FIG. 103.—Schematic diagram showing principle of time-limit acceleration by means of mercury-timer relay.

247A. Synchronous-motor timer relays consist of a set of contacts driven from the shaft of a very small synchronous motor, so that there is a definite time lag between the starting of the motor and closing of the contacts. A controller utilizing such a relay is described in Sec. **287.**

248. Acceleration controlled by means of inductive time-limit contactors or relays makes use of the inductive time-lag effect of the decay of current in a heavily inductive circuit. This method of timing is often

called magnetic timing. In controllers employing this method, each accelerating contactor may be of the inductive time-limit type, or of the ordinary shunt type with each controlled by means of an inductive-time relay. Inductive time-limit contactors may be of the normally open-contact (holdout type) or of the normally closed type.

249. An inductive time-limit accelerating contactor of the normally open-contact type (Fig. 104) consists of a pivoted armature acted upon by two coils located on opposite sides of the pivot point. The main operating coil acts to close the contactor, while the auxiliary coil acts to hold the contactor open. In the diagram of the controller of Fig. 105 the coils marked 2*R*, 3*R*, 4*R*, and 5*R* are the main operating coils of the respective inductive time-limit contactors 2*R*, 3*R*, 4*R*, and 5*R*. The coils marked *HC*2, *HC*3, *HC*4, and *HC*5 are the holdout coils of the contactors 2*R*, 3*R*, 4*R*, and 5*R*, respectively.

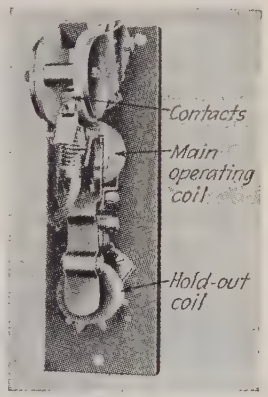
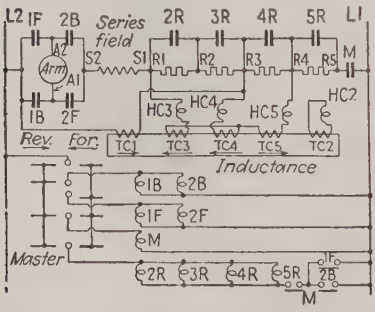


FIG. 104.—Inductive time-limit contactor of the normally open-contact type. (*Cutler-Hammer.*)

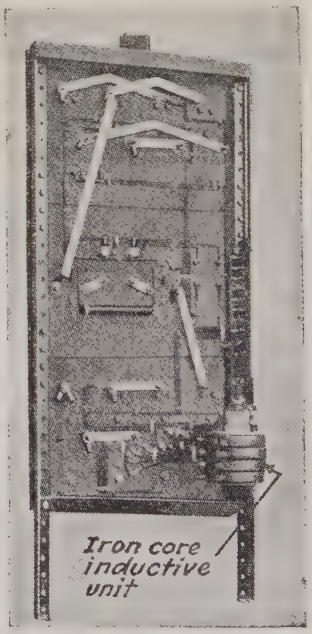
249A. The principle of controlling the acceleration by means of inductive time-limit accelerating contactors of the normally open-contact type is illustrated by the typical control diagram of Fig. 105, I. In addition to the contactors, an iron-core inductive unit is required. This inductance consists of a set of coils *TC*1, *TC*2, *TC*3, *TC*4, and *TC*5 wound on a common iron core. The inductance assembly is shown mounted on the back of the control panel in Fig. 105, II. In starting from rest, if the operator moves the master switch to the running position for forward direction of rotation, the circuits of operating coils 1*F*, 2*F*, and *M* are closed. These coils operate their respective contactors, causing contacts 1*F*, 2*F*, and *M* to close. This connects the motor across the line in series with all the starting resistance. Voltage will be impressed upon coils *TC*1, *TC*3, *TC*4, and *TC*5, causing these coils to be energized and to hold out their respective contactors. But the coils are so connected that the m.m.fs. of the coils just neutralize each other so that no flux is produced in the core. There is therefore no current in the closed circuit of coils *HC*2 and *TC*2, and contactor 2*R* is free to close when its operating coil is energized. As soon as contactors 1*F* and *M* have closed, auxiliary contacts on these contactors close the circuits of the operating coils 2*R*, 3*R*, 4*R*, and 5*R*. Contactor 2*R* immediately closes, shorting out the section of resistance $R_1 - R_2$ and shorting coil *HC*3 through *TC*3. This unbalances the m.m.fs. of the inductance, and a definite flux is produced in the core. This change in flux and the inductance of coils *HC*3 and *TC*3 oppose the decay of current in *HC*3 and *TC*3. After a certain

lapse of time the current in $HC3$ will drop to nearly zero. The holdout coil $HC3$ of the contactor $3R$, being now de-energized while its main coil $3R$ is energized, causes contactor $3R$ to close. The closing of contactor $3R$, shorting coils $HC4$ and $TC4$, again unbalances the flux. After a definite time lapse, the current in $HC4$ will drop to nearly zero, and contactor $4R$ will close. Closing of $4R$ shorts coils $HC5$ and $TC5$ and once again unbalances the flux. After another definite time interval the current in $HC5$ drops to nearly zero, and contactor $5R$ is allowed to close. The motor is then connected directly to the line.

When plugging, *i.e.*, throwing from full speed in one direction to full speed in the other, it is desired to have a time delay in the closing of contactor $2R$. Coil $TC1$ is connected across the armature and resistance $R_1 - R_2$. The current through coil TC_1 therefore depends upon



I



II

FIG. 105.—Inductive time-limit acceleration. (I) Schematic diagram of connections. (II) Rear view of control panel, showing inductance assembly. (*Cutler-Hammer.*)

the sum of the voltage across the armature and the resistor $R_1 - R_2$. The voltage across the armature when starting from rest is very low, but when plugging it is normal line voltage. In plugging, therefore, the current through $TC1$ is much higher than it is when starting from rest. This larger current through $TC1$ unbalances the m.m.fs. of the inductance and produces a flux which induces a current in shorted coils $HC2$ and $TC2$. This induced current will hold out contactor $2R$ until the current has had time to reduce to nearly zero.

249B. The principle of time-limit acceleration by means of inductive time-limit contactors of the normally closed-contact type is illustrated

in Fig. 107. A contactor of this type is shown in Fig. 106. A copper tube encircles the magnetic core of the contactor, over which two operating coils are wound. These two coils act in opposition to each other. When the main winding is open circuited after having been carrying current, the magnetic flux decreases. This decrease in flux induces a heavy current in the enclosed copper tube. The induced current opposes the decay of the flux so that there is a considerable lapse of time after the circuit of the main coil is opened before the flux decays sufficiently to allow the armature to be released. The length of time delay will depend upon the original value of the flux, which can be controlled by adjustment of the current in the neutralizing winding.

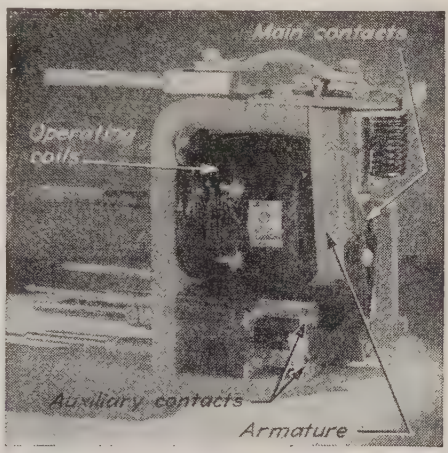


FIG. 106.—Inductive time contactor of the normally closed-contact type. (*Westinghouse Type A Q Timetactor.*)

Acceleration is automatically performed in the following manner: When the start button is pressed, current flows from *L*1, through stop and

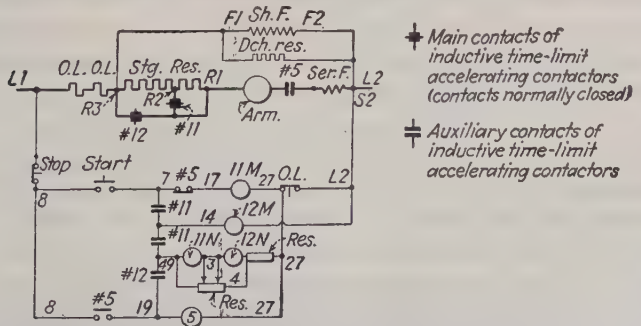


FIG. 107.—Schematic diagram showing principle of time-limit acceleration by means of inductive time-limit contactors of normally closed-contact type.

start contacts to 7, through contacts $\frac{5}{}$, operating coil (11 M), contacts $\frac{\text{O.L.}}{}$, and back to line *L*2. The armature of contactor 11 is therefore

attracted, opening its main contacts 11 and closing its auxiliary contacts 11. The closing of the two sets of auxiliary contacts 11 energizes main operating coil (12 M) and neutralizing coils (11 N) and (12 N). The armature of contactor 12 is therefore attracted, opening its main contacts and closing its auxiliary contacts 12. This energizes the operating coil (5), which closes the main line-contactor 5. The motor is then connected to the line in series with all the starting resistance. When contactor 5 closes, it opens its auxiliary contacts 5 and closes its auxiliary contacts 5. The closing of contacts 5 keeps the operating circuits of the contactors energized when the start button is released. Opening of contacts 5 opens the main operating coil circuit (11 M) so that after a definite time, determined by the adjustment of the resistances controlling (11 N) and (12 N), contactor 11 drops out and thereby closes its main contacts, shorting out the resistance $R_1 - R_2$. At the same time, auxiliary contacts. 11 are opened, which opens the circuit of the main operating coil (12 M). After a definite time the flux of contactor 12 decreases a sufficient amount so that contactor 12 drops out, closing its main contacts and shorting out resistance $R_3 - R_2$. The motor is now connected directly across the line. As contactor 12 drops out, its auxiliary contact 12 opens, which disconnects all the operating coils of the accelerating contactors. In case of an overload, the operating coils or bimetallic heater elements open the contacts O.L., de-energizing the operating coil (5) of the main-line contactor so that the motor is disconnected from the line and will not start up again until pressing the start button again starts the above sequence of starting operations. To stop the motor, the stop button is pressed, which opens the circuit of the operating coil (5) of the main-line contactor.

249C. Acceleration by means of inductive time relays requires the use, for each step of resistance, of an ordinary shunt contactor in conjunction with a magnetic time relay. A magnetic time (inductive-time) relay may be constructed in just the same manner as the inductive-time accelerating contactors of the normally closed-contact type described in Sec. **248.** The only differences are that it is smaller in size and that its main contacts are not capable of carrying as heavy currents. The principle of operation in obtaining acceleration by this means is shown in

Fig. 108. The same general system of symbols is used as given in Sec. 249B and Fig. 107. The main contacts of the line contactor are $\overset{5}{\dashv\vdash}$. The contacts of the regular shunt-coil accelerating contactors are $\overset{3}{\dashv\vdash}$ and $\overset{4}{\dashv\vdash}$. The main contacts of the inductive-time-limit relays are $\blacksquare$ 11 and $\blacksquare$–12. When the start button is pressed, current flows from $L1$ through the stop and start buttons to 7, through contacts $\overset{5}{\circ\!\circ}$, operating coil $\overset{11}{(M)}$, contacts $\overset{O.L.}{\circ\!\circ}$, and back to line $L2$. The armature of relay 11 is therefore attracted, opening its main contacts $\blacksquare$ 11, which opens the circuit of operating coil ③. At the same time auxiliary contacts $\overset{11}{\dashv\vdash}$ close, thus energizing operating coil $\overset{12}{(M)}$ and neutralizing coils $\overset{11}{(N)}$ and $\overset{12}{(N)}$. The armature of relay 12 is therefore attracted, opening its main contacts $\blacksquare$–12, which open the circuit of operating coil ④. At the same time auxiliary contacts $\overset{12}{\dashv\vdash}$ close, energizing operating coil ⑤, which closes the main-line contactor 5. The motor is then connected to the line in series with all the starting resistance. When contactor 5 closes, it closes its auxiliary contact $\overset{5}{\circ\!\circ}$ and opens its auxiliary contact $\overset{5}{\circ\!\circ}$. The closing of $\overset{5}{\circ\!\circ}$ makes power available for the operating coils when the start button is released. Opening of contact $\overset{5}{\circ\!\circ}$ opens the main operating-coil circuit $\overset{11}{(M)}$, so that after a definite time determined by the adjustment of the resistances controlling the neutralizing coils $\overset{11}{(N)}$ and $\overset{12}{(N)}$, relay 11 drops out and thereby closes its main contacts $\blacksquare$ 11. Closing of contacts $\blacksquare$ 11 energizes the operating coil ③, which operates contactor 3, shorting out the resistance $R_2 - R_3$. As relay 11 drops out, it opens its auxiliary contacts $\overset{11}{\dashv\vdash}$, which open the circuit of the main operating coil $\overset{12}{(M)}$ of relay 12. After a definite time, the flux of relay 12 decreases a sufficient amount so that relay 12 drops out, closing its main contacts $\blacksquare$–12 and energizing the operating coil ④. Operating coil ④ closes the contacts of contactor 4, which short out the resistance $R_3 - R_4$. The motor is now connected directly across the line. As relay 12 drops out, its auxiliary contacts $\overset{12}{\dashv\vdash}$ open, which disconnects all the operating coils of the accelerating relays.

249D. Time acceleration controlled by means of the time required to charge a condenser is a relatively new development introduced by the Electric Controller & Manufacturing Co. and called neotime acceleration. This method applied to a d-c motor is shown in Fig. 108*A*. When the start button is pressed, current flows from *L*1 through the start and stop buttons, through the operating coil (*M*) and back to *L*2. This energizes the operating coil (*M*) of the main-line contactor, which closes its contacts $\overset{M}{\dashv\vdash}$ and connects the motor across the line in series with all the

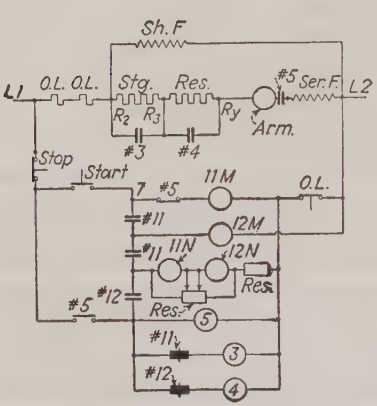


Fig. 108.

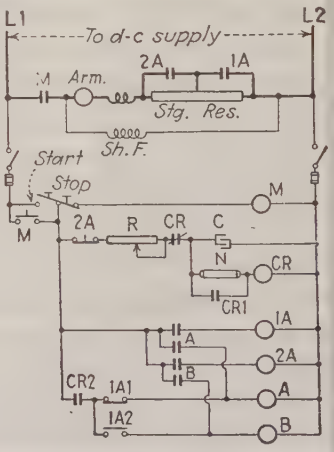


Fig. 108*A*.

Fig. 108.—Schematic diagram showing principle of operation of time-limit acceleration by means of inductive time-limit relays.

Fig. 108*A*.—Schematic diagram showing principle of time-limit acceleration by means of condenser-charge method applied to a d-c motor. (*Neo-time acceleration of Electric Controller & Manufacturing Co.*)

starting resistance. When contactor *M* closes, it also closes its auxiliary contacts $\overset{M}{\dashv\vdash}$, which provide a means of supplying power to the operating coils when the start button is released. Current will also flow through contacts $\overset{2A}{\dashv\vdash}$, resistance *R*, contacts $\overset{CR}{\dashv\vdash}$, and condenser C. After a certain time delay depending upon the value of resistance *R* and the capacity of the condenser *C*, the voltage across the condenser will reach the ignition voltage of the neon tube *N*. The gas of the tube will then break down and become conducting so that current will pass through tube *N* and the operating coil (*CR*) of relay *CR*. Relay *CR* then operates and closes the two sets of contacts $\overset{CR1}{\dashv\vdash}$ and $\overset{CR2}{\dashv\vdash}$ and opens contacts $\overset{CR}{\dashv\vdash}$. Closing of contacts $\overset{CR2}{\dashv\vdash}$ allows current to flow through $\overset{1A1}{\dashv\vdash}$

and operating coil (A) of relay *A*. Relay *A* operates, closing its two sets of contacts $\overset{A}{\dashv\vdash}$, which allow current to flow through operating coil -(1A)- and also provide a permanent path for current through operating coil (A) so that the relay will be held closed upon the opening of $\overset{CR2}{\dashv\vdash}$ contacts. Operating coil -(1A)- causes contactor 1*A* to close its contacts $\overset{1A}{\dashv\vdash}$, thus shorting out a section of the starting resistance. The opening of $\overset{CR}{\dashv\vdash}$ contacts and closing of $\overset{CR1}{\dashv\vdash}$ contacts disconnect the condenser from the supply and provide a discharge path for the condenser through the coil -(CR)-. It takes only about $\frac{1}{20}$ to $\frac{1}{30}$ sec. for the condenser to discharge, so that operating coil -(CR)- is very rapidly de-energized, and contacts $\overset{CR1}{\dashv\vdash}$ and $\overset{CR2}{\dashv\vdash}$ open and contacts $\overset{CR}{\dashv\vdash}$ close before contactor 1*A* closes. This starts the condenser on another charging cycle. When contactor 1*A* closes, it opens its auxiliary contacts $\overset{1A1}{-\circ\ \circ-}$ and closes its auxiliary contacts $\overset{1A2}{-\circ\ \circ-}$. After a certain time the condenser again is charged to a sufficient voltage so that the neon tube breaks down and again operates relay *CR*. Current will then flow through contacts $\overset{CR2}{\dashv\vdash}$, $\overset{1A2}{-\circ\ \circ-}$, and the operating coil (B) of relay *B*. Relay *B* closes its two sets of contacts $\overset{B}{\dashv\vdash}$, which allow current to flow through the operating coil -(2A)- and also provide a permanent path for current through operating coil (B), so that the relay *B* will remain closed upon the opening of $\overset{CR2}{\dashv\vdash}$ contacts. Operating coil -(2A)- causes contactor 2*A* to close its contacts $\overset{2A}{\dashv\vdash}$; thus shorting out the other section of resistance and connecting the motor directly across the line. When contact 2*A* closes, it also opens its auxiliary contacts $\overset{2A}{-\circ|\circ-}$, which open the condenser and tube timing circuit.

In the application of this method of acceleration to a-c motors (Fig. 108*B*) it is necessary to use two auxiliary relays for each accelerating contactor except the last one. Alternating-current contactors close much more rapidly than d-c ones, and, if the additional auxiliary relay were not employed, an accelerating contactor would close before the *CR* relay could drop out. The operating coil of the next accelerating contactor would be immediately energized, and thus two accelerating contactors would close at one operation of the condenser timer with practically no time lag between the closing of the two accelerating contactors. In using this system on an a-c circuit it is necessary to provide a d-c source for charging the condenser. This is done by means of a small radio potential transformer connected to a full-wave rectifier tube as shown in

Fig. 108*B*. The action of the timing circuit is exactly the same as for the d-c application previously described. In starting the motor the first operation of relay *CR* allows current to flow through contacts $\overset{CR2}{\dashv\vdash}$, contacts $\overset{}{\circ\!-\!\circ}_{1A\,3}$, and the operating coil Ⓒ of auxiliary relay *C*. Relay *C* closes its two sets of contacts $\overset{C1}{\dashv\vdash}$ and $\overset{C2}{\dashv\vdash}$. The closing of contacts $\overset{C1}{\dashv\vdash}$ causes relay *A* and contactor 1*A* to function in the same manner as previously described for d-c operation. The closing of contact $\overset{C2}{\dashv\vdash}$ and opening of contacts $\overset{C}{\dashv\vdash}$ keep relay *C* closed and the circuit of operating coil Ⓑ open until relay *CR* has had time to open. The second functioning of the timing circuit and operation of relay *CR* causes relay *B* and contactor 2*A* to function, thus connecting the motor directly to the line.

249E. With current-limit acceleration the cutting out of the various steps of starting resistance, or the changing of taps on an autotransformer, is controlled by the decay of the starting current as the motor accelerates. The rapidity of the closing of the successive contactors depends upon the load on the motor. With light loads the motor will accelerate on each step more rapidly so that the current decreases more rapidly and causes the successive contactors to function in a shorter length of time. The total length of time for the starting period therefore depends upon the load.

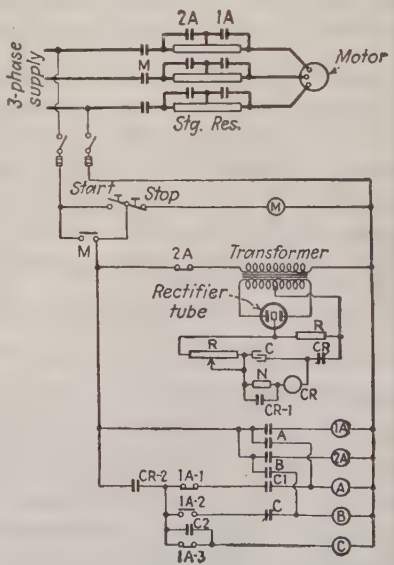


Fig. 108*B*.—Schematic diagram showing principle of time-limit acceleration by means of condenser-charge method applied to a polyphase squirrel-cage motor. (*Neo-time acceleration of Electric Controller & Manufacturing Co.*)

Current-limit acceleration is performed by means of series contactors of the types described in Sec. **240**. Acceleration may be accomplished by using series contactors of the single-coil type as shown in Fig. 108*C*. Pressing the start button energizes the operating coil ③ of the main line contactor 3 so that line contacts $\overset{3}{\dashv\vdash}$ close, connecting the motor to the

line in series with the starting resistance. When the starting current has decreased to the value for which the series contactor 4 is adjusted, operating coil (4) closes its contactor 4. The closing of contacts $\overset{4}{\dashv\vdash}$ shorts out the section of resistance $R_7 - R_8$ and allows the starting current to pass through operating coil (5) of the second series accelerating contactor. When the starting current has decreased to the value for which the series contactor 5 is adjusted, operating coil (5) closes its contactor 5. Closing of contacts $\overset{5}{\dashv\vdash}$ shorts out all the starting resistance and also the main operating coils of contactors 4 and 5, so that there will be no danger of these contactors dropping out under light loads. Contactor 5 has an auxiliary shunt holding coil $\overset{5}{\sim\!\sim}$ which holds this contactor closed after

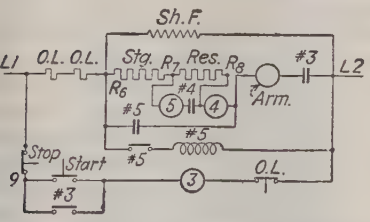


FIG. 108*C*.—Schematic diagram showing principle of current-limit acceleration by means of series contactors of the single coil type.

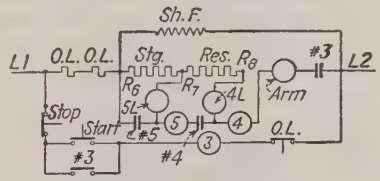


FIG. 108*D*.—Schematic diagram showing principle of current-limit acceleration by means of series contactors of the two coil type.

t has once been closed by its main operating coil (5). When contactor 5 closes, it also closes its auxiliary contacts $\overset{5}{\frown\!\circ\!\circ\!\frown}$, thus energizing the auxiliary holding-coil circuit for the contactor. The motor is now connected directly to the line.

The method of controlling acceleration by means of two-coil, series, lockout contactors (Sec. **24**) is shown in Fig. 108*D*. Pressing the start button energizes the operating coil (3) of the main-line contactor 3 so that line contacts $\overset{3}{\dashv\vdash}$ close, connecting the motor to the line in series with the starting resistance. When the starting current has decreased to the value below that for which the lockout coil (4*L*) of contactor 4 will hold this contactor open, contactor 4 closes its contacts $\overset{4}{\dashv\vdash}$. This shorts out the section of starting resistance $R_7 - R_8$ and the lockout coil (4*L*) of contactor 4 so that the contactor will not drop out under light loads. The current now passes through the operating coil (5) and lockout coil (5*L*) of contactor 5 which locks open until the current has dropped to a value to the amount for which the contactor is adjusted to operate. When the current has dropped to this value, contactor 5 closes its con-

tacts $\overset{5}{\dashv\vdash}$, which short out the resistance $R_6 - R_7$ and the lockout coil (5L). With the lockout coils shorted out, these contactors do not need any auxiliary shunt holding coil, since the series operating coils will hold the contactors closed with only about 5 per cent of their normal current. The motor is now connected directly across the line.

249F. Counter-e.m.f. acceleration is really a special method of current-limit acceleration, since the current that flows through the motor depends upon the value of the counter-e.m.f. It is applicable only to d-c motors. The time required for the starting period will depend upon the load on the motor just the same as for the other current-limit acceleration methods.

In controlling acceleration by the counter-e.m.f. method the operating coils of the magnetic contactors are connected across the armature winding (Fig. 108*E*). At standstill no counter-e.m.f. is produced in the armature winding. As soon as the motor starts to revolve, a counter-e.m.f. is generated in the armature winding. The counter-e.m.f. is directly proportional to the speed so that, as the motor speeds up, the counter-e.m.f. increases. Since the operating coils of the magnetic contactors are connected across the armature, their operation depends upon the value of the counter-e.m.f. The magnetic contactors are adjusted so that it requires a definite value of counter-e.m.f. to operate each one, a higher value of counter-e.m.f. being required to operate each successive contactor. When the speed has reached a value so that the counter-e.m.f. is sufficient to operate one of the contactors, the contactor closes and shorts out a section of the starting resistance.

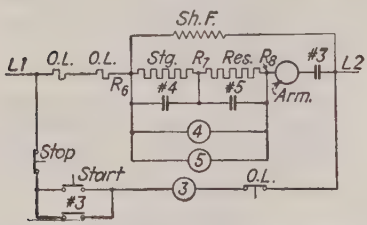
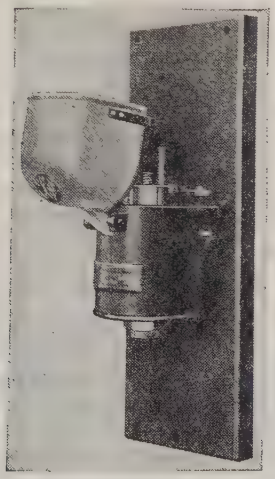


FIG. 108*E*.—Schematic diagram showing principle of counter-e.m.f. acceleration.

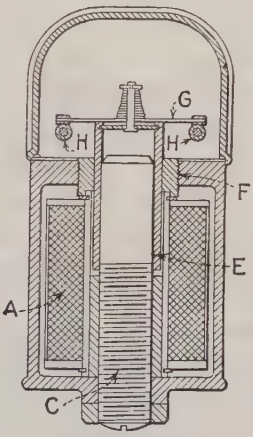
249G. Time-current control of acceleration, as the name implies, is a combination of time and current control of the accelerating period. With time control the time of acceleration is entirely independent of the load on the motor, while with current control the time of acceleration depends entirely upon the load on the motor. With time-current control, the time of acceleration is modified by the load on the motor but is not entirely dependent upon the load.

One method of obtaining time-current control of acceleration is through the use of the time-current acceleration relay of Fig. 108*F*. This relay consists of a series operating coil *A*, an adjustable steel core *C*, an air gap *F*, a movable circular aluminum sleeve *E*, carrying the movable contacts *G*, and a set of stationary contacts *H*. When the circuit of the operating coil is closed, the current changes in a very short time from zero to some

definite value, depending upon the circuit in series with which the coil is connected. A magnetic flux is built up rapidly in the iron core C, and air gap F. This flux also links with the aluminum sleeve E, which forms a closed single-turn conductor. The rapid change of flux linked with the sleeve E causes considerable current to be induced in the sleeve. The current through the operating coil and the induced current in the aluminum sleeve are in such directions that they produce a repelling force between the coil and the sleeve. The sleeve is therefore rapidly propelled upward upon the closing of the operating-coil circuit. The parts



I. Complete relay.



II. Cross-section view.

FIG. 108*F*.—Time-current relay. (*Electric Controller & Manufacturing Co.*)

are so designed that considerable force is exerted upon the sleeve, and it would travel 1 ft. or more if it were not for the fact that, as the tube starts to move, it passes through the field F, which now causes eddy currents to be set up in the sleeve. These eddy currents cause a retarding action, just the same as a wattmeter vane is retarded as it is forced through a magnetic field, and this, combined with the force of gravity, stops the sleeve, which then starts to fall under the force of gravity. Inasmuch as current still flows through A, causing flux in F, the sleeve is likewise retarded by eddy currents in the downward direction the same as it is retarded in the upward direction. This retarding action therefore provides a time delay, which may be as much as 2.75 sec., in the closing of contacts G and H. The length of time will be dependent upon the current in A and the adjustment of the steel core C. Since the current in A determines the strength of the flux in F, C, and E, it will be seen that a lower current in A will cause the sleeve to jump less distance, and the

retarding action in the downward direction will be less so the time also will be less. In practice, the current in A is the same as the motor current so that when heavy current flows in the motor due to a heavy load the time will be longer, and when the motor current is less as on light loads the time will be less. Hence we have time-current control; *i.e.*, a system of control where the time is modified by the current or load on the motor.

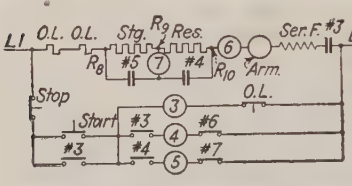


FIG. 108*G*.—Schematic diagram showing principle of time-current acceleration by means of a magnetic time-current relay.

The maximum time of operation can be adjusted by moving the adjustable steel core C. Moving the core changes the air gap F. Adjusting C so as to increase the air gap will shorten the maximum time of operation.

The principle of time-current control of acceleration with these time-current relays is illustrated by the elementary control circuit of Fig. 108*G*. When the start button is pressed, the operating coil ③ of the main-line contactor 3 is energized. Contacts $\overset{3}{\dashv\vdash}$ close and connect the motor to the line in series with the starting resistance. Upon the closing of contactor 3 current passes through the operating coil ⑥ of time-current relay 6, and the auxiliary contacts $\overset{3}{\frown\!\circ\!\circ\!\frown}$ of the contactor 3 close. Current will start to flow through operating coil ④, but before its contactor 4 has time to close its contacts $\overset{4}{\dashv\vdash}$, the aluminum sleeve of relay 6 has been raised and opens the contacts $\overset{6}{\frown\!\circ\!\circ\!\frown}$ of this relay, thereby opening the circuit of operating coil ④. After a time delay depending upon the setting of relay 6 and the load on the motor, the aluminum sleeve of relay 6 drops and recloses contacts $\overset{6}{\frown\!\circ\!\circ\!\frown}$. The operating coil ④ of contactor 4 is now energized and contactor 4 operates, closing its contacts $\overset{4}{\dashv\vdash}$. This shorts out the resistance $R_9 - R_{10}$, closes auxiliary contacts $\overset{4}{\frown\!\circ\!\circ\!\frown}$, and energizes the operating coil ⑦ of time-current relay 7. Current will start to flow through the operating coil ⑤ of contactors 5, but before the contactor can close, the aluminum sleeve of relay 7 has jumped up and opened the contacts $\overset{7}{\frown\!\circ\!\circ\!\frown}$. After a time delay, the aluminum sleeve of relay 7 drops, reclosing the contacts $\overset{7}{\frown\!\circ\!\circ\!\frown}$ of this relay and energizing the operating coil ⑤ of contactor 5. Contactor 5 now operates and closes its contacts $\overset{5}{\dashv\vdash}$. The motor is now connected directly to the line.

249H. Time-current acceleration utilizing the principle of the time required to charge a condenser is a new development of the Electric Controller & Manufacturing Co. This method is similar to the time-limit acceleration method described in Sec. **249D** with the addition of other condensers, resistors, and a second rectifier so that the time of charging of condenser C is modified by the motor current. The application of this method to a squirrel-cage motor is shown in Fig. 108*H*. The d-c source of power for charging the condenser C is obtained from the voltage across two load resistors supplied by two rectifiers connected in series. The rectifiers are so connected that their voltages oppose each other. The voltage produced by one rectifier is controlled by the motor current through the series transformer which supplies rectifier tube RT-2. The combined voltage for operating the timer is thus modified by the motor current. The greater the motor current the lower the combined voltage for charging condenser C, and therefore the time for the condenser to become charged will be increased.

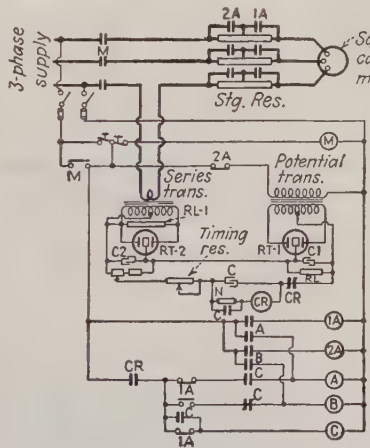


FIG. 108*H*.—Schematic diagram showing principle of time-current acceleration by means of condenser-charge method. (*Neo-time-current method of Electric Controller & Manufacturing Co.*)

249I. Frequency control of acceleration is a new development of the Electric Controller & Manufacturing Co. for application to wound-rotor induction motors. The operation of the frequency relays employed in this method depends upon the action of resonant circuits. An a-c circuit which contains both inductance and capacity will be resonant at some definite frequency, depending upon the value of the inductance and the capacity. At the resonant frequency, such a circuit will pass a very much higher value of current than at any other frequency. The current of such circuits will increase with frequency up to the resonant frequency. The operating coils of the frequency relays, which have a certain value of inductance, will produce a resonant circuit when connected in series with an external condenser. By using condensers of different capacities with a set of relays, the respective relays will become resonant at different frequencies (Fig. 108*I*). The higher the capacity the lower is the resonant frequency.

The application of this method of acceleration to a wound-rotor induction motor is shown in Fig. 108*I*. The relays *PR*, 1*AR*, 2*AR*, and 3*AR* are frequency relays. Each relay operating coil in series with its condenser is connected to a potentiometer rheostat so that it can be adjusted to the proper current. The relays are supplied with power from the secondary resistor so as to receive a maximum voltage of 90 volts, on 60-cycle circuits, when the motor primary is first connected to the line. The relays have normally closed contacts. After a relay has attracted its armature, the armature will not drop out until the current of the operating coil has dropped to a certain value. The frequency at which the current reaches the drop-out value will vary with the resonant frequency of the circuit. The higher the resonant frequency the higher the frequency at which the dro-pout current will be reached. The relays are connected in series with progressively larger values of capacity, so that the resonant frequencies of the relays progressively decrease. The drop-out currents will occur at progressively lower frequencies. At standstill the frequency of the secondary circuit of an induction motor is the same as that of the primary supply circuit and decreases as the speed of the motor increases. It is approximately zero at full speed. The frequency relays will therefore drop out progressively as the motor accelerates. The operation of the motor illustrated may be controlled manually by moving the master controller to successive positions, or the acceleration may be made fully automatic by throwing the master to the last position. If the master is thrown to the last position forward, when the motor is at rest, the master contacts *MF*, *F*, *P*, 1*A*, 2*A*, and 3*A* will all be closed. The motor will then be automatically accelerated as follows: Operating coils (*M*) and (*F*) are first energized, which operate contactors *F* and *M* and close contacts $\frac{F}{\dashv\vdash}$ and $\frac{M}{\dashv\vdash}$. Closing of contactor *F* closes its auxiliary contacts $\frac{F}{\circ\ \circ}$. The motor is now connected to the

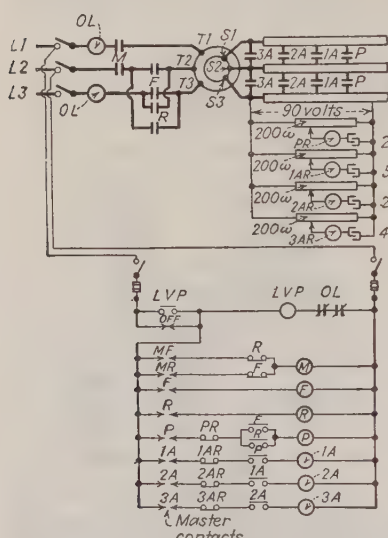


FIG. 108*I*.—Schematic diagram showing principle of frequency acceleration.

line with resistance in its rotor circuit. The starting current in the rotor circuit energizes the operating coils PR, $1AR$, $2AR$, and $3AR$ of all the frequency relays. The relay PR, which is the plugging relay and which has only $2\frac{1}{2}$ mfd. in series with its coil, will not pass enough current to operate. Since all the frequency relays have normally closed contacts, the contacts $\frac{PR}{\circ\ \circ}$ of relay PR will stay closed, and operating coil $-(P)-$ of contactor P will be energized. Thus contactor P will close its contacts $\frac{P}{\dashv\vdash}$ immediately. The frequency relays $1AR$, $2AR$, and $3AR$ will operate immediately upon passage of current through the motor and therefore will open their contacts $\frac{1AR}{\circ\ \circ}$, $\frac{2AR}{\circ\ \circ}$, and $\frac{3AR}{\circ\ \circ}$. Closure of contactor P closes its auxiliary contacts $\frac{P}{\circ\ \circ}$, but operating coil $-(1A)-$ will not be energized until relay $1AR$ drops out and closes its contacts $\frac{1AR}{\circ\ \circ}$. Relay $1AR$ will drop out after the motor has accelerated to a sufficient speed so that the frequency of the rotor is such as to cause the current of operating coil $-(1AR)-$ to decrease to the drop-out value. When relay $1AR$ drops out, it closes its contacts $\frac{1AR}{\circ\ \circ}$ and energizes the operating coil $-(1A)-$ of contactor $1A$. Contactor $1A$ then operates and closes its contacts $\frac{1A}{\dashv\vdash}$, shorting out some of the resistance. In a similar manner as the motor accelerates, frequency relays $2AR$ and $3AR$ drop out at progressively higher speeds and cause contactors $2A$ and $3A$ to close.

250. Methods of Starting D-c Motors.—As discussed in Sec. **136,** d-c motors are almost always started with resistance in series with the armature winding. Both manual and automatic starters are used.

251. Available Types of Controllers for D-c Motors

Type	Remarks
1. Manual starters:	
a. Across the line	Available in nonreversing and reversing types without dynamic braking
b. Starting rheostats (dial-type starters)	Suitable only for nonreversing service without dynamic braking
c. Drum	Suitable for nonreversing and reversing service with or without dynamic braking
d. Multiple switch	Suitable only for nonreversing service without dynamic braking
2. Manual-starting and speed-regulating controllers:	
a. Starting and speed-regulating rheostats (dial-type controllers)	Suitable only for nonreversing service without dynamic braking
b. Drum	Suitable for nonreversing and reversing service with or without dynamic braking
3. Magnetic starters:	
a. Time-limit acceleration *b.* Current-limit acceleration *c.* Counter-e.m.f.-limit acceleration *d.* Time-current acceleration	Available in nonreversing and reversing types with or without dynamic braking

252. Across-the-line starters for d-c motors are made as standard equipment in sizes up to and including 2 hp. They consist of some form of safety-enclosed manually operated switch made in a rugged and compact manner. They may be obtained with or without thermal over-

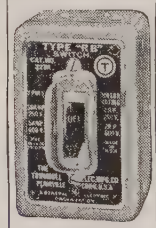
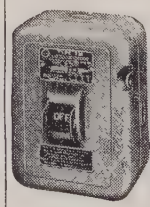
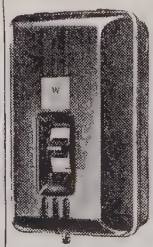
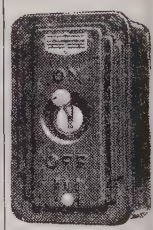
Approximate hp. range	Trumbull Electric Manufacturing Company	General Electric Company	Westinghouse Electric & Manufacturing Company	Cutler-Hammer
Up to ¼ hp., without overload protection				
Fractional horsepower, different types vary from up to ¼ hp. to up to ¾ hp., all have thermal overload protection				
Up to 2 hp., all have thermal overload protection				

FIG. 109.—Typical across-the-line starters for d-c motors.

load release devices. Those of the smaller types are sometimes called auxiliary or secondary breakers (see Div. 4). Most of the overload release devices are of the automatic self-resetting type, so that, after the occurrence of an overload, service is restored by simply throwing the handle to the extreme "off" and then to the "on" position. The release mechanism generally is constructed on the trip-free principle so that the

switch cannot be held closed against a dangerous overload. These starters cannot be provided with undervoltage release or protective devices. Typical starters of these types are shown in Fig. 109.

253. Starting rheostats for d-c motors, sometimes called dial or face-plate starters, consist of a series of contacts mounted on an insulating panel and connected to different points in a resistance unit (see Fig. 110). An arm or dial bearing a contact is arranged so that it can be moved across the stationary row of contacts. A starting rheostat is shown in Fig. 111, and wiring diagrams of similar starters in Fig. 110. Moving the arm to the first contact closes the armature circuit in series with the starting resistance. As the arm is moved across the buttons, sections of the starting resistance are successively cut out of the circuit, until the last contact is reached. Then all the resistance has been cut out of the circuit, and the armature is connected directly across the line. These starting rheostats are not suitable for reversing or dynamic braking service. They may be used for starting series, shunt, or compound-wound motors.

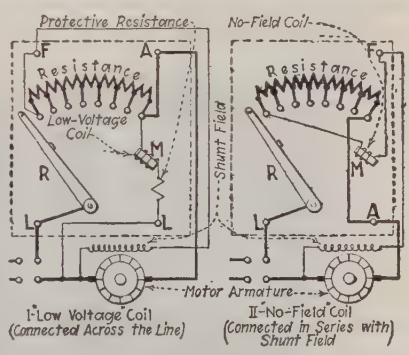


FIG. 110.—Diagram showing low-voltage protection provided by low-voltage coil and by a no-field coil.

254. Undervoltage protective devices for starting rheostats may be operated by either a low-voltage coil or a no-field coil (Fig. 110). On a manually operated starter, each device usually consists of an electromagnet M, which under conditions of normal voltage holds the operating arm R in the running position, and a spring (not shown in the diagram) which returns the operating arm to the "off" position upon failure or decrease of voltage. Starters are sometimes so constructed that instead of the electromagnet being made strong enough to hold the arm in the running position against the force of the spring, a catch is provided which will engage and hold the arm after it has been manually moved to the running position. Then, if the voltage drops below a predetermined value, the electromagnet disengages the catch. This releases the arm, which is returned to the "off" position by the spring. The magnet coil may be connected directly across the line (Fig. 110, I) with a protective resistance in series, in which case it is called a low-voltage coil, or it may be connected in series with the shunt field (Fig. 110, II), in which case it is called a no-field coil. Both arrangements provide low-voltage protection. If the coil is connected across the line, the current carried by the

coil, and therefore the coil losses, will be less than if it is connected i series with the shunt field. The difference between the maximum an minimum field currents of wide-speed-range, adjustable-speed moto renders it impractical to design a series-connected holding coil which w operate satisfactorily throughout the range. The General Electric an the Westinghouse starters regularly have the holding-magnet coil co nected across the line. Upon request, the starters will be furnished wit the coil in series with the shunt field. The Cutler-Hammer Co. furnish

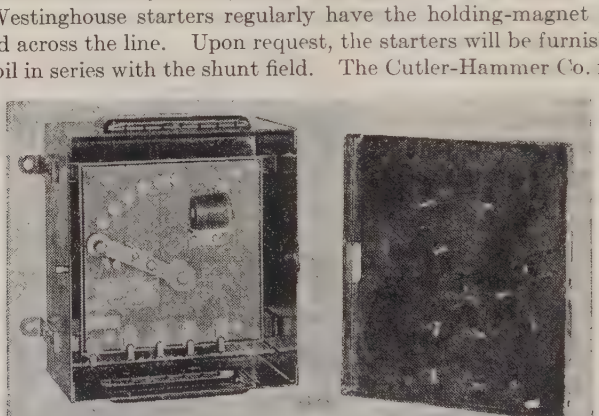
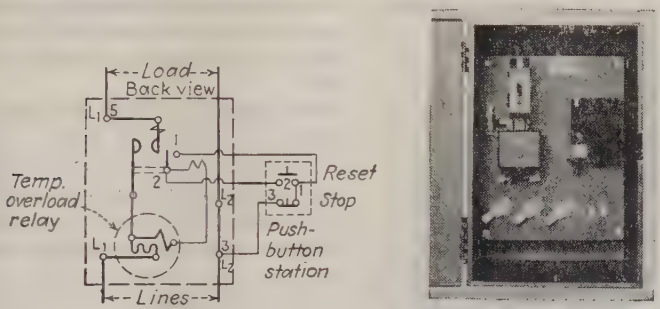


FIG. 111.—Starting rheostat of dial type for d-c motor. (*General Electric C*

its starters for constant-speed motors with the coil in series with t shunt field, and for adjustable-speed motors with the coil across the lin If, with the coil connected across the line, the shunt-field circuit shou accidentally open, the motor might "run away" and destroy itse With the coil in series with the shunt field, this would not occur. Starte having undervoltage protection (provided by either a no-field or a lo voltage coil) will not permit a reestablished voltage to be automatica impressed upon the motor. This feature is imperative in applicatio where the unexpected return of the voltage might endanger the operat or the motor. From the standpoint of general safety the no-field-c arrangement is preferable.

255. In starting a d-c motor (see Fig. 111), close the line switch a move the operating arm of the rheostat step by step over the contac waiting a few seconds on each contact for the motor speed to accelera If this process is performed too quickly the motor may be injured excessive current; if too slowly, the rheostat may be injured. If t motor fails to start on the first step, move promptly to the second st and if necessary to the third, but no farther. If no start is made when t third step is reached, open the line switch at once, allow the starter han to return to the "off" position, and look for faulty connections, overlo etc. The time of starting a motor with full-load torque should not, a general thing, exceed 15 sec. for rheostats for motors of 5 hp. and les output, and 30 sec. for those of greater output.

256. In stopping a d-c motor, open the line switch. The arm will return automatically to the "off" position. Never force the operating arm of any starting rheostat back to the "off" position.



I. Connections. II. Unit assembled in enclosing case

FIG. 112.—Overload protective unit for use with a motor starting rheostat. (*General Electric Co.*)

FIG. 113.—Combination starting rheostat and fused safety switch. (*Cutler-Hammer.*)

257. Overload protection is not generally provided in starting rheostats. Overload protection must be provided at some other point in the motor circuit by means of fuses, circuit breakers, safety switches with thermal overload protection, or magnetic contactors controlled by overload relays. A typical magnetic-contactor protective unit is illustrated in Fig. 112.

Some manufacturers make combination units which combine either fused switch or a circuit breaker in the same mounting with the starter as illustrated in Figs. 113 and 114. For some installations these combination units are very desirable. They concentrate all the motor control apparatus at one point and, where this is advantageous, simplify the wiring.

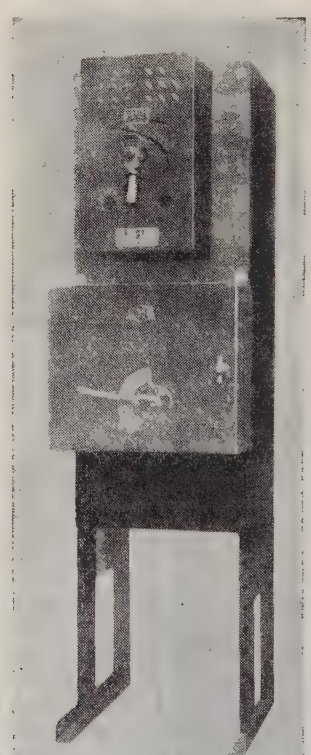


FIG. 114.—Combination starting rheostat and circuit breaker. (*Cutler-Hammer.*)

258. Drum-switch starters are made in a variety of types. They can be obtained for both reversing and nonreversing service and with or without contacts for dynamic braking. They are used for series, shunt, and

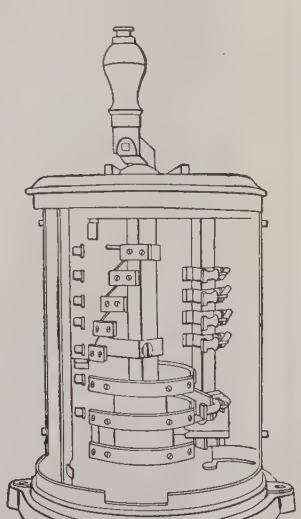


FIG. 115.—Reversing drum controller with cover removed. (*Westinghouse Electric & Manufacturing Co.*)

compound motors. The essential features of a drum starter are a central movable drum upon which are mounted a set of contact segments and a set of stationary contact fingers. A typical drum starter is illustrated in Fig. 115. The movement of the drum is controlled by means of a handle on top of the starter case. As this handle is moved from the "off" position, the armature circuit is closed in series with the starting resistance by means of the first set of movable segments on the drum making

contact with the first set of stationary fingers. As the handle is moved around, the resistance is short-circuited step by step by the contacts located farther around on the drum. Small starters of this type are self-contained with the starting resistance mounted in a ventilated box on the rear of the drum switch. In the larger sizes the resistance is mounted separately from the drum switch. Drum controllers do not provide any overload or undervoltage protection. Overload protection may be provided by fuses or a circuit breaker mounted separate from the controller. A magnetic contactor with an overload relay will provide both overload and undervoltage protection. Such a protective unit has the advantage that it may be electrically interlocked with the drum switch so that the line contactor cannot be closed unless the drum switch is in the "off" position. This safeguards against the possibility of the motor being thrown directly across the line. Connections for a typical magnetic-contactor protective panel are shown in Fig. 116. Its appearance would be similar to the protective unit of Fig. 112.

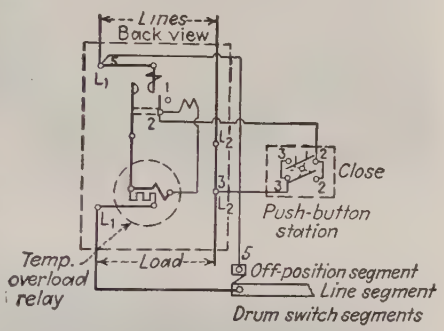
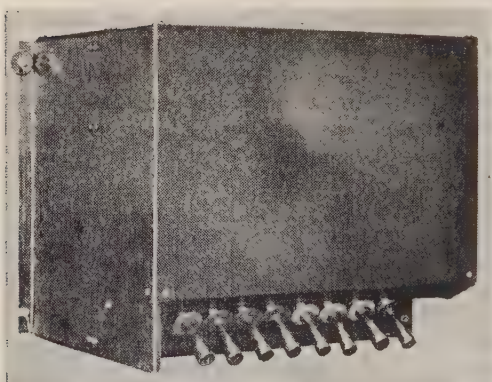


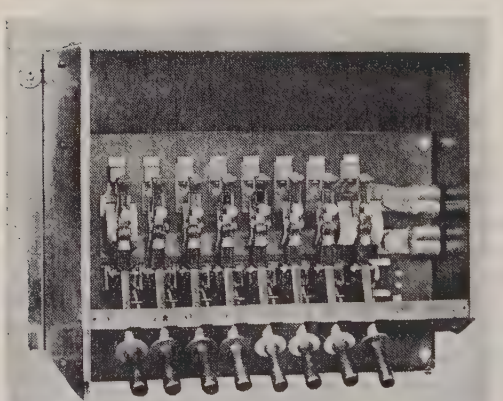
Fig. 116.—Diagram of connections for magnetic overload protective unit for use with drum starter.

259. The manually operated multiple-switch starter for d-c motors (Fig. 117) comprises a number of switches S, which are manually closed in sequence. Thereby the resistances R are shunted out of circuit as the armature accelerates. The switches are so mechanically interlocked that their being closed in any other than the proper sequence is prevented. When the last switch S_5 is closed, all the resistance is short-circuited. The switches, after being closed, are held in the closed position by a latch. This catch is in turn held by a low-voltage-protective magnet M.

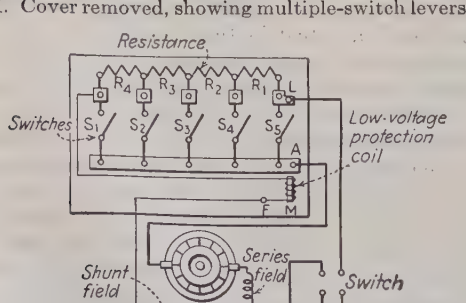
Upon the failure of voltage, the catch is released, and all the switches are thrown to the "off" position by gravity or by a spring. A switch of this type is especially adapted for starting large motors. A sufficient time period will elapse in the ordinary closing of the switches to provide protection against too rapid acceleration. The arrangement of a number of switches in parallel tends to minimize heating of the contacts, particularly of the contact of the last switch S_5. One of the contact blocks of each switch is often made of laminated copper strips and the other of carbon. The laminated brushes and the copper-to-carbon wiping contacts render a switch of this type exceptionally adaptable for use with large motors. Overload protection must be provided out-



I. Enclosed view.



II. Cover removed, showing multiple-switch levers.



III-Connection diagram

FIG. 117.—Multiple-switch starter.

side the starter These starters are suitable for series, shunt or compound motor in nonreversing service without dynamic braking.

260. Apparatus for Field Control of Shunt or Compound Motors.—The variable resistance in series with the shunt field necessary for speed control of shunt or compound motors by the field-control method, may be provided by means of a field rheostat separate from the starting rheostat or the starting rheostat and the field rheostat may be combined into a single piece of equipment forming a combined starting and speed-adjusting controller. Such combined starting and speed-adjusting controllers are available in both the dial and the drum types of construction.

261. Field relay switches are required where separate rheostats are used for starting and controlling the speeds of motors. This is required by a National Electrical Code rule to prevent the possibility of starting a motor with

veakened field. The switch shown in Fig. 118, which is mounted nder the starter handle, accomplishes this function by short-circuiting he field rheostat during acceleration so that the motor must always tart with full field regardless of the position of the field-rheostat arm. The switch shown, or a similar one, can be applied to ordinary start- ng and speed-regulating rheostats and generally should be mounted on he rheostat at the factory of the firm that furnishes it.

The field relay switch shown consists of a small electromagnet, a ivoted switch bar, and a stationary contact. The switch bar is normally eld away from the contact by a helical spring. The magnet coil, switch ar, and contact are in series with a circuit that parallels the field rheostat.

When the operating arm of the starting rheostat is moved to the rst step, a pin on its hub presses the relay switch bar against its station- ry contact, thus short-circuiting the field rheostat. As the arm is urned, the pin on the starter hub soon releases the relay switch bar; but he relay electromagnet, energized when the contacts close, holds this bar emporarily in place. The winding f the relay electromagnet is so pro- ortioned that, if there is little or o resistance in series with the mo- or shunt field, the relay magnet ill release the switch bar before he motor is brought to full speed, aving the field rheostat available r speed adjustment. But if the eld-rheostat arm is turned so that here is more resistance in series ith the shunt field than would be fe to insert in one step, the elec- omagnet will keep the relay vitch closed until the arm of the eld rheostat is brought back to- ard the "off" position. A vi- ating type of relay as described Sec. **272** may be used for ensur- g full field during acceleration of e motor.

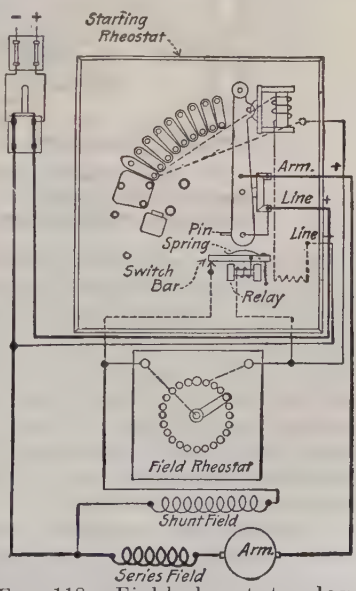


FIG. 118.—Field-rheostat relay switch.

262. Starting and Speed-adjust- g (Field-control) Rheostats for -c Shunt- and Compound-wound otors.—There are as many (and ore) designs as there are manufacturers, but the equipment shown in gs. 119 and 120 is typical and can be used for starting and regulating eed in nonreversing services where speed adjustment by field control is sirable. The apparatus is so arranged that the motor is always started

with full field strength. In case of failure of the voltage, the field-contro resistance is automatically short-circuited, and the motor is disconnecte from the line.

The rheostat consists of a faceplate carrying the contacts, operatin arms, and safety devices, mounted in connection with two resistors One is for starting and one for adjusting the field strength. The face plate carries three rows of stationary contacts. The upper row is con nected with the field-adjusting resistor, the second row with the startin resistor; and the lowest row contains a long curved segment for short circuiting the field-resistance in starting. A contact for short-circuiting the armature resistance when the arm is in the running position is sometimes provided.

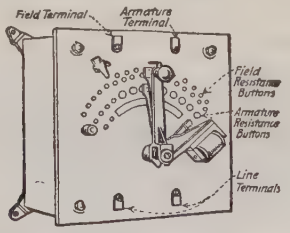


FIG. 119.—Starting and speed-adjusting rheostat, removed from enclosing box.

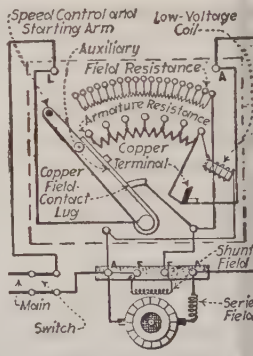


FIG. 120.—Wiring diagra for starting and spee adjusting rheostat.

The faceplate supports two arms, an operating arm and a short-circui ing arm, pivoted to the same hub and arranged so that they cannot pa each other. The operating arm carries the handle and two conta fingers, one for the starting contacts and the other for the field contact The short-circuiting arm has a contact finger which slides over the co tact bar, short-circuiting the field resistance in starting, and the armatu resistance while running. In some designs this arm also carries laminate copper brushes which short-circuit the starting resistance when the ar reaches the running position. A spring tends to return the short-circui ing arm to the off position.

Under conditions of normal operation the short-circuiting arm is he in the running position against the force of the spring by an electromagn connected across the line in series with a protecting resistance. If t voltage falls below a predetermined point, the arm is released and retur to the "off" position, carrying the operating arm with it.

263. Operation of a Starting and Speed-adjusting Rheostat (Figs. 1 and 120).—The motor is started by moving the operating arm to t running position, stopping a few seconds on each starting contact to pe mit the speed to accelerate. The retaining magnet holds the sho

circuiting arm in the running position where it short-circuits the starting resistor. The operating arm is then moved back over the field-resistance contacts until the desired speed is reached. For motors starting with full-load torque, the time of acceleration should be from 15 to 30 sec., depending upon the capacity of the motor. To stop the motor, open the line switch. Both arms then return to the "off" position automatically.

264. Drum controllers for combined starting and speed adjustment (field control) are provided with two sets of contacts, one set for the control of the starting resistance, and the other set for controlling the speed of

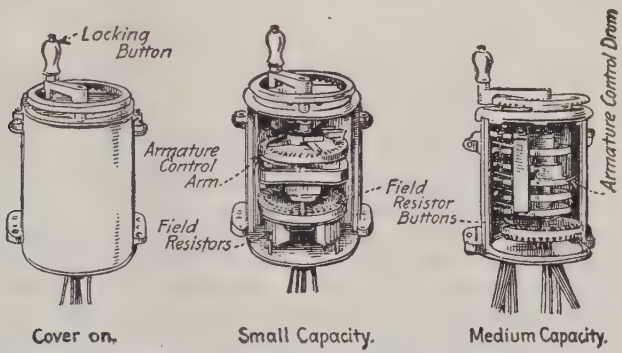


FIG. 121.—Machine-tool controller.

the motor through the variation of the shunt-field resistance. Although controllers of this type (Fig. 121) find their most frequent applications on machine tools, they are very desirable for any service where the work is severe and where the expense of a controller is justified. Machine-tool work usually requires a combination starting and speed-regulating controller, *i.e.*, one whereby the motor is started by cutting out armature resistance. After the motor is started, its speed is regulated by varying the amount of resistance in series with the shunt field. These controllers can be purchased for this service and for control or starting service of practically any type. The methods of construction and connection are so numerous that only one type of drum controller, one which is used for machine-tool service, will be described here.

Advantages of controllers of this type are that the contacts and arm are entirely enclosed and that the movement of a single handle in one direction or the other starts the motor in a corresponding direction and brings it to the running speed desired. The operating arm remains securely locked at the proper notch until released by the operator by pressing a button in the handle.

There are two switching devices in the controller shown in Fig. 121. One connects to the armature or starting resistor, and the other connects

to the field-control resistor. Both switching devices are operated by the same handle. In drum controllers of small capacity the armature switching device consists of an arm passing over contact buttons, and all the resistors are mounted within the drum; *i.e.*, the controller is self-contained. In controllers of large capacity, the armature resistance is cut in and out by a rotating drum similar to that used in street-railway service, and all the resistors are mounted external to the controller. The field resistance is cut in and out by a rotating arm passing over contact buttons in all but the largest controllers, for which a drum is used. Arc shields between drum segments and blowout coils are provided where necessary. The controllers can be arranged to provide dynamic braking. Speed ranges of from 1:2 to possibly 1:6 are usually provided.

265. Operation of Drum-type Machine-tool Controllers (Fig. 121).—Continuous movement of the operating handle in either direction first starts the motor in the corresponding direction of rotation, then cuts out the starting resistance, and finally cuts in the field resistance until the desired running speed is reached. The handle should be moved over the starting notches in not over 15 sec. for motors of possibly 10-hp. capacity and in not over 30 sec. for larger motors. The starting resistance should not be used for speed control.

For a quick stop when operating with weakened field, move the handle quickly to the first running notch, hold it there momentarily, and then move it to the "off" position; the application of full field strength when the speed is high causes dynamic braking, thus checking the speed quickly and without shock. For a very quick emergency stop, the handle can be moved to the first reversing notch after checking the speed by dynamic braking, but this operation causes severe mechanical and electrical stresses; this reversing should never be carried beyond the first notch. When the motor is to be at rest for any length of time, open the line switch.

266. Apparatus for Armature Speed Control of D-c Motors.—When armature speed control is employed, the same piece of equipment serves for both starting and speed control. An ordinary starting controller should not be used for armature speed control, however, as it is designed not for continuous duty but only for intermittent service as is required in starting. In employing a controller for armature speed control, one must make sure that it is designed for that type of service and not simply for starting duty. Controllers suitable for armature control are available in both the rheostat and the drum types.

267. Rheostat-type, armature-control speed regulators (Fig. 122) are used for speed reduction with shunt, compound, or series motors in nonreversing service where the torque required decreases with the speed but remains constant at any given speed as with fans, blowers, and centrifugal pumps. They can also be used for applications where the torque is independent of the speed, as with job printing presses. However,

this method of speed control is not suitable for such applications where there is operation for long periods at reduced speed, since such operation is not economical. It is not possible, where the torque varies, to obtain constant speed with these controllers.

In the regulator shown, the low-voltage release consists of an electromagnet enclosed in an iron shell, a sector on the pivot end of the operating arm, and a strong spring which tends to return the arm to the "off" position. The magnet is mounted directly below the pivot of the arm,

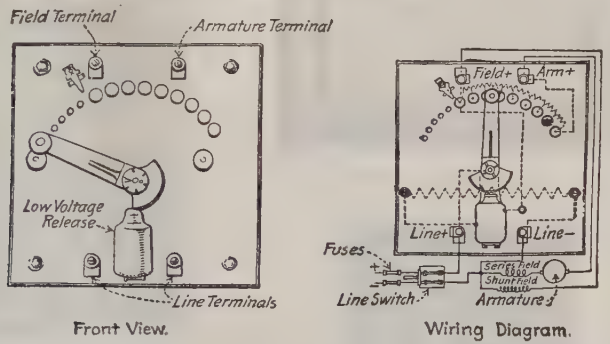
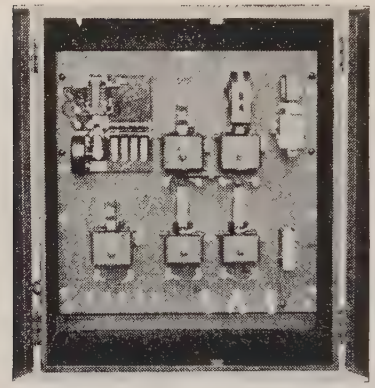


FIG. 122.—Armature-control speed regulator, removed from enclosing box.

and its coil is connected in shunt across the line in series with a protecting resistance. When the magnet is energized its plunger rises and forces a steel ball into one of a series of depressions in the sector on the arm with sufficient force to hold the arm against the action of the spring; each depression corresponds to a contact. The arm can be easily moved by the operator, however, as the ball rolls when the arm is turned. When the voltage fails, the magnet plunger falls and the spring throws the operating arm to the "off" position. An overload release, similar to that described in another paragraph, which operates by opening the low-voltage-coil circuit, is sometimes furnished on regulators of this type. Standard commercial rheostats of this type are designed to give about 50 per cent speed reduction on the first notch. See the following paragraph on operation for further information.

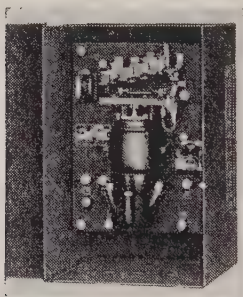
268. Operation of Armature-control Speed Regulators (Fig. 122).—Continuous motion of the operating arm starts the motor and brings it gradually to maximum speed. Moving the arm over the first few contact buttons increases the shunt-field strength if the motor is shunt or compound. The movement over the succeeding buttons cuts out armature resistance and permits the motor to speed up.

269. Drum controllers suitable for armature speed control are widely used for crane and hoist motors and in railway applications. Their general appearance and construction is the same as the drum starter

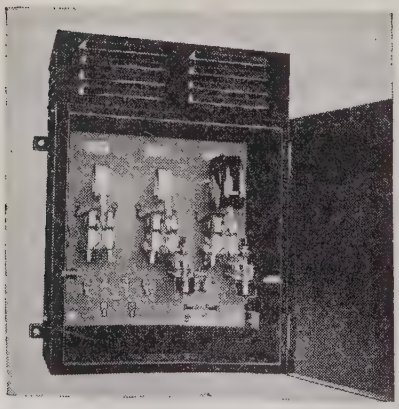


I. Escapement type

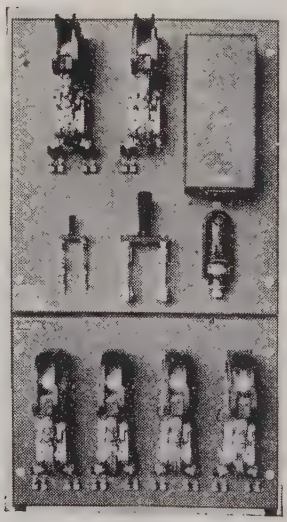
II. Inductive time-limit



III. Oil dashpot type



IV. Mercury timer



V. Condenser charge

FIG. 123.– For legend see opposite page.

shown in Fig. 115. Crane controllers are arranged for reversing service and usually for dynamic braking.

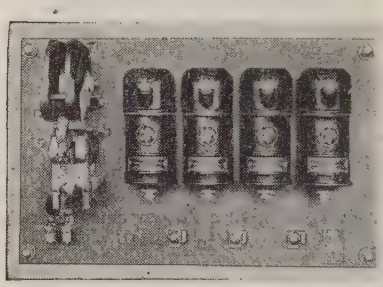
270. Controllers for combined armature and field speed control are manufactured in both the rheostat and the drum types. With this type of controller the speed may be either increased above normal by means of field control or decreased below normal by means of armature control. They are employed when a greater speed range is desired than can be obtained with field control alone and also for fan service. They also find a limited application in machine work. Controllers of this type for fan and machine service are arranged usually to give a 25 per cent increase in speed by field control and 50 per cent decrease in speed by means of armature control.

271. Magnetic starters for d-c motors are available in a large number of different types for reversing and nonreversing duty, with or without dynamic braking and for inching and jogging service. They may be used with constant-speed or adjustable-speed shunt or compound motors and with series motors. When used with adjustable-speed motors, speed control is obtained by means of a field rheostat mounted separately from the magnetic controller.

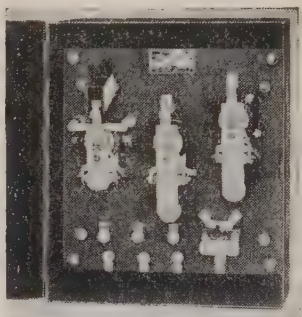
Where armature speed control is required, it is obtained by controlling the functioning of the contactors by means of a master controller. The operator adjusts the master controller to the position for the desired speed, and this initiates the functioning of the contactors, which adjusts the resistance to the corresponding value.

Magnetic starters consist of the necessary magnetic contactors and relays mounted on a panel and generally enclosed in a sheet-metal cabinet. Practically all magnetic starters and controllers are equipped with some form of overload protective relay which opens the circuit of the operating coil of the line contactor upon the occurrence of an overload on the motor. The master switch for initiating the operation of the controller may consist of an automatic float or pressure switch, a push-button switch, or a drum or rotary switch. The automatic switches and the push-button masters are used for simple control such as starting and stopping or starting, stopping, and reversing, while the drum or rotary switch is employed where full speed control by the operator is required, as for the control of cranes, hoists, etc. "No-voltage protection" or release is provided through the operating coil of the main-line contactors, since upon failure or abnormal reduction of the line voltage, the operating coil of the contactor will be de-energized, and the contactor will open the motor circuit. The principles of the different methods of automatically controlling the acceleration are discussed in Secs. **243** to **249H.**

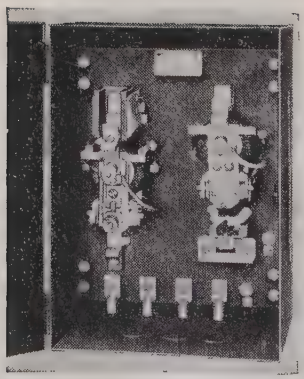
FIG. 123.—Typical time-limit controllers for d-c motors. I, *General Electric Co.;* II, *Cutler-Hammer;* III, *Ward Leonard Electric Co.;* IV, *Electric Controller & Manufacturing Co.;* V, *Electric Controller & Manufacturing Co.*



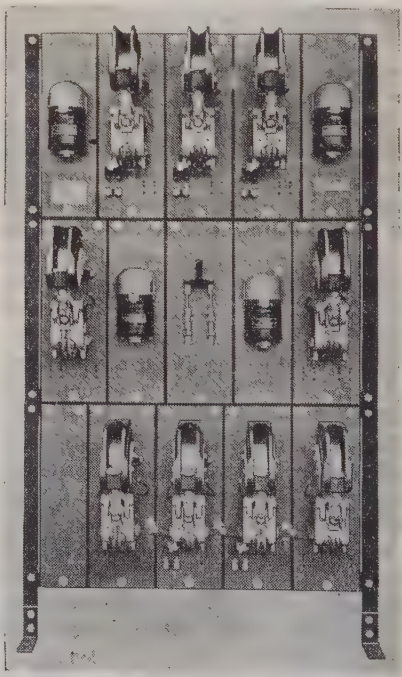
I. Current-limit type. (*Electric Controller and Manufacturing Co.*)



II. Current-limit type. (*Ward Leonard Electric Co.*)



III. Counter-e.m.f. type. (*Ward Leonard Electric Co.*)



IV. Time-current type. (*Electric Controller & Manufacturing Co.*)

FIG. 124.—Typical magnetic controllers for d-c motors.

The appearance of typical magnetic controllers is shown in Figs. 123 and 124.

272. Field relays must be used with magnetic starters when field speed control is employed. This is necessary in order to ensure that the motor will be started with full field. These relays are called vibrating or fluttering relays, since during the acceleration or deceleration of the motor their armatures flutter or vibrate between the open and closed position, alternately shorting and cutting in the field resistance. The operating coil of the relay is connected in series with the armature of the motor, and the contacts are connected across the shunt-field rheostat. During the starting period, whenever the armature current exceeds the value for which the relay is set, the relay will close, short-circuiting the field resistance so that the field strength is maximum. After the starting resistance in series with the armature has been cut out of the circuit, the field relay will hold in until the motor has accelerated sufficiently to reduce the armature current to the value which will allow the field relay to drop out. As it drops out, the field resistance will be cut into the field circuit, thus weakening the field strength. This weakening of the field reduces the counter-e.m.f. and therefore will cause the armature current to increase and further accelerate the motor. The increase in armature current causes the field relay to close again, short-circuiting the field resistance. This action is rapidly repeated, the relay vibrating between open and closed positions until the motor has been accelerated to the speed for which the field rheostat is adjusted. The armature current is then at its normal value and is not sufficient to operate the field relay, which remains open with the field resistance cut into the field circuit.

273. Methods of Starting Polyphase, Squirrel-cage Induction Motors.

1. Full-voltage (across the line).
2. Reduced voltage.
   a. By means of autotransformer (compensator)
   b. By means of series resistor.
   c. By means of series reactor.

Any polyphase induction motor can be safely started by applying full voltage at starting without harm to the motor, but, as discussed in Sec. **132,** the heavy starting current drawn from the line by this method may produce too great power and voltage fluctuations in the power-supply system. When the starting current must be reduced, one of the methods listed in (2) above is employed for reducing the voltage impressed on the motor during starting. In method *a* the motor is connected at start to the secondary of an autotransformer. After the machine has accelerated sufficiently, the motor is switched over to full line voltage. With this method there are just two steps in the sequence of starting operations: reduced voltage of some definite value and then directly to full line volt-

age. Starters employing the transformer method of reducing the voltage are called compensators or autotransformer starters. In method *b*, resistance is connected in series with the motor leads from the supply. One or more steps of resistance may be employed. In most cases only one step is used so that the motor is first connected to the line with some definite value of resistance in series, and then, after the machine has accelerated sufficiently, it is thrown over to full line voltage. Where the starting conditions are more severe or the starting current must be more closely regulated, additional steps are employed for cutting out the resistance. Method *c* is similar to the series-resistance method except that reactance is inserted in series with the motor during starting instead of resistance. With this method only one step of reactance is used.

For the same value of starting torque developed, the autotransformer method of starting will limit the first value of peak starting current to the lowest value. The amount of power consumed during the starting period will be considerably less than with resistance starting. A disadvantage of this method is that the motor is generally entirely disconnected from the supply during the transition period from reduced to full line voltage. This causes a second peak current to be drawn from the line at the instant that full voltage is applied. Some power companies will not allow the use of autotransformer starters for this reason.

With resistance starting, the motor is connected to the supply continuously throughout the starting period, the motor impressed voltage being increased by shorting out the starting resistance. Although there will be an increase in line current whenever some or all of the starting resistance is short-circuited, the magnitude of such peaks will not be nearly so great as the peak current involved at the instant when full voltage is applied with autotransformer starting. The resistance-starting method has the advantage that it produces very smooth starting conditions with respect both to strains imposed upon the motor and load and to the power and voltage fluctuations produced in the supply circuit during the starting period. Resistance starting is used in cases where the strains imposed upon the load with compensator starting would be detrimental or where this method is required by power-supply-company regulations. The resistance method is not generally satisfactory unless a starting torque of 50 per cent or less of full-load torque is sufficient.

With series-reactance starting, the same as in resistance, the motor connections do not have to be broken during the starting period. The reactor is short-circuited when the motor attains its maximum speed on reduced voltage. For the same current drawn from the line, reactance starting will develop the same starting torque as resistance starting. Reactance starting has the advantages over resistance starting that less power is consumed during the starting period and that the transition peaks of current will be less, owing to the opposing effect of the inductance to sudden changes in the current. For the same number of steps, reac-

ance starting will produce the smoothest starting conditions of any of the three methods of starting. However, in the smaller sizes, control equipment of this type is more expensive than either of the other two and for all sizes is more expensive than resistance starting. It is not practicable to make reactance starters for more than two steps of starting control, so that, by using a greater number of steps, smoother starting can be obtained with resistance starting. For many large motors, a reactance starter will be cheaper than a transformer starter, since only two sets of switching contacts are required for a one-step starter as compared to

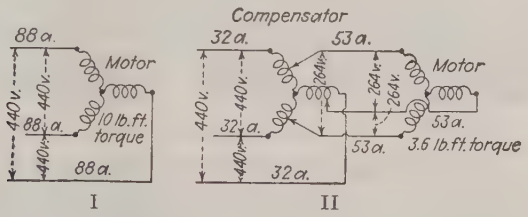


FIG. 125.—Starting with and without compensator.

three sets for a transformer starter. For these reasons, reactance starting is utilized only in the case of very large motors when one or two steps of starting will be satisfactory.

On account of the lower cost of across-the-line starters the general practice is to use this type of starting wherever it is possible to use motors whose starting currents are within the allowable limits.

274. Starting with and without Compensators.—The starting current taken by a squirrel-cage induction motor at the instant of starting is equal to the applied e.m.f. divided by the impedance of the motor. Only the duration of this current, and not its value, is affected by the torque against which the motor is required to start. The effect of starting without and with a compensator is illustrated by diagrams *I* and *II* in Fig. 125. In this diagram, motor *I* is thrown directly on a 440-volt line. The impedance of the motor is 5 ohms per phase; the starting torque, 10 lb. at 1 ft. radius; and the current taken, 88 amp. In diagram *II* a compensator is inserted, stepping down the line voltage from 440 to 60 per cent of 440 or 264 volts. This reduces the starting current of the motor to 60 per cent of 88 or 53 amp., and the starting torque becomes $(0.6)^2 \times 10$ or 3.6 lb. at 1 ft. radius. The current in the line is reduced to 60 per cent of 53 or 32 amp.

Thus when a compensator is used the starting torque of the motor can be reduced to approximately the value required by the load and the current taken from the line correspondingly decreased.

275. Comparison of Autotransformer and Resistance for Decreasing Voltage for Starting Squirrel-cage Motors.—The motor in Fig. 126 is

supposed to require 100 amp. to start it, *i.e.*, to provide the energy needed to produce the necessary starting torque. At *I*, where an autotransformer is used to lower the voltage to 110, a current of 100 amp. is produced in the motor primary with a current in the line of 50 amp. This condition is due to the transformer action of the autotransformer. At *II* the running connections are shown wherein the autotransformer is entirely disconnected from the circuit. At *III* are illustrated the conditions that would obtain were the voltage lowered for starting by inserting resistance in series with the line. Obviously 100 amp. must flow in all portions of the line even though the resistance of 1.1 ohms reduces the line voltage of 220 to a voltage of 110, which is impressed on the motor. There is a loss of energy in the resistance. For the same line starting current the starting torque available with the resistance method will be considerably less than that developed when a compensator is employed. As was stated in Sec. **273,** the resistance-starting method has the advantage that it produces very smooth starting conditions with respect to both the strains imposed upon the motor and load and the voltage fluctuations produced in the supply circuit during the starting period. A comparison of starting torques and currents when reducing the voltage in the two different ways is given in Table 276.

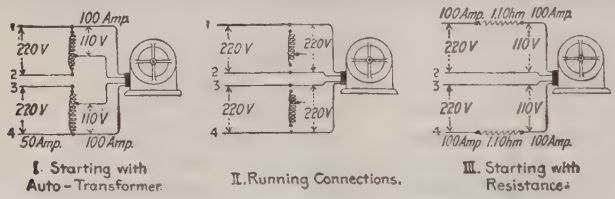
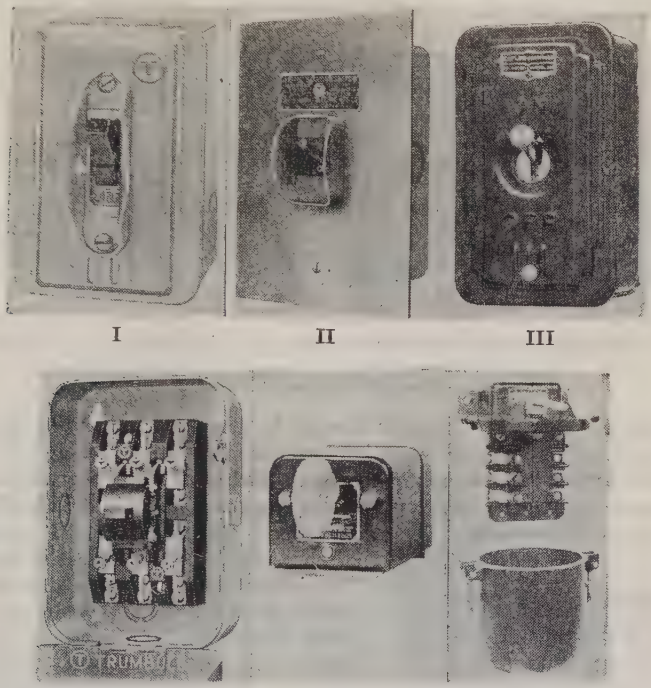


FIG. 126.—Starting with resistance and with compensator.

276. Comparison of Starting Characteristic with Primary-resistance and Compensator Starting

Voltage impressed on motor in percentage of normal voltage	Starting current taken directly by motor in percentage of full-voltage starting current (same for both methods)	Starting current taken from line in percentage of full-voltage starting current		Starting torque in percentage of full-voltage starting torque
		Compensator starting	Resistance starting	
50	50	25	50	25
65	65	42	65	42
80	80	65	80	65

277. Across-the-line starters are made in a variety of different types. Starters of the same general type differ from each other in details of con-



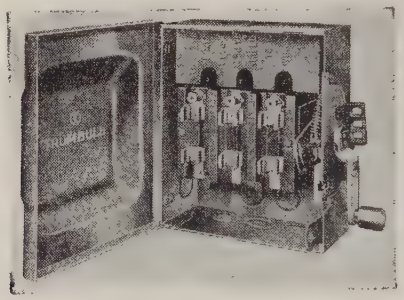
I. Tumbler type—surface mounting. (*Trumbull Electric & Manufacturing Co.*)
II. Tumbler type—flush mounting. (*Trumbull Electric & Manufacturing Co.*)
III. Tumbler type. (*Cutler-Hammer.*)
IV. Tumbler reversing type. (*Trumbull Electric & Manufacturing Co.*)
V. Drum type. (*General Electric Co.*)
VI. Rotary, reversing, oil immersed type. (*General Electric Co.*)

FIG. 127.—Typical plain motor starting switches without overload protection for polyphase squirrel-cage motors.

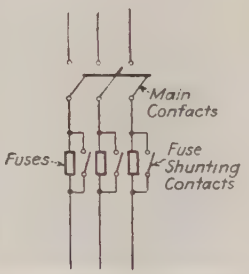
struction, depending upon the ideas of the manufacturer. The most common types of across-the-line starters are given in the following list:

1. Plain motor-starting switch with no overload protection.
2. Two-position, fusible motor-starting switch.
3. Single-throw switch with thermal overload protection.
4. Magnetic switch with thermal overload protection.
5. Circuit breaker with time-limit overload protection.

278. The plain motor-starting switch is simply a tumbler, rotary, lever, or drum switch constructed in an especially rugged manner. It does not provide any overload or undervoltage protection. It is used



I. Switch assembled in enclosing case.



II. Diagram of connections.

FIG. 128.—Two-position motor-starting switch.

for nonreversing duty in small sizes up to 2 hp. and for reversing duty up to 15 hp. Some representative types are illustrated in Fig. 127.

279. Across-the-line, motor-starting switches of the two-position type are made in a variety of forms differing from each other in details of construction. The fundamental principle of these switches is illustrated in Fig. 128. One set of switch contacts is connected in series with fuses in the line leads to the motor. A second set of switch contacts operated from the same lever as the main switch is connected across the fuses. When the switch is thrown from the "off" to the "on" position, both sets of switch contacts are closed. This shunts the fuses out of the circuit and allows the starting current to pass without blowing the fuses. When the operating handle is released, the auxiliary switch contacts, which shunt the fuses, automatically open, while the main switch remains closed. It is impossible to leave the switch in such a position that the fuses are continually shunted out of the circuit. These starting switches do not provide any undervoltage protection.

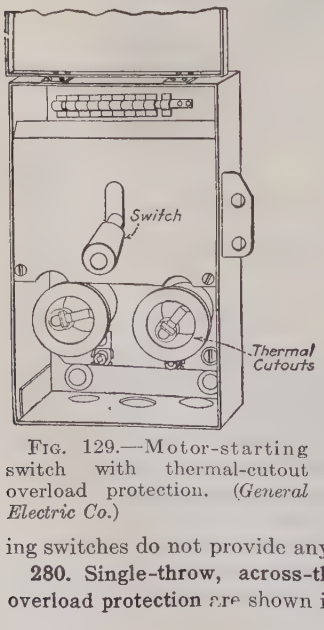
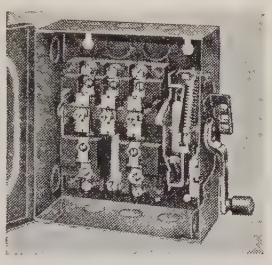


FIG. 129.—Motor-starting switch with thermal-cutout overload protection. (*General Electric Co.*)

280. Single-throw, across-the-line starting switches with thermal overload protection are shown in Figs. 129 and 130. The thermal over-

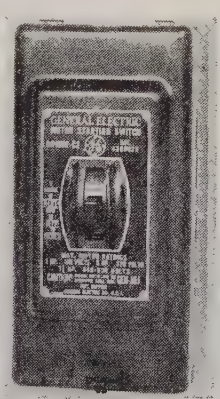
load protection may be obtained by means of thermal cutouts, as in the switches shown in Fig. 129, by means of time-lag fuses, or by means of a thermal overload release device as in the switches shown in Fig. 130.

I. Front operated. (*Trumbull Electric & Manufacturing Co.*)



II. Side operated. (*Trumbull Electric & Manufacturing Co.*)

III. Push-button operated. (*Ward Leonard Electric Co.*)



IV. Front operated. (*General Electric Co.*)

FIG. 130.—Typical manual single-throw across-the-line starting switches with thermal overload protection for polyphase squirrel-cage induction motors.

When thermal cutouts or time-lag fuses are used, the cutouts or fuses must be replaced after their rupture by an overload. With thermal overload releases there is nothing to renew after the occurrence of an overload. For a more complete discussion of the principles of thermal overload protective devices refer to Div. 4. In the switches of Fig. 130 the thermal overload release device, when actuated by an overload, trips the holding

catch of the switch and allows the switch to open. These starters do not provide any undervoltage protection.

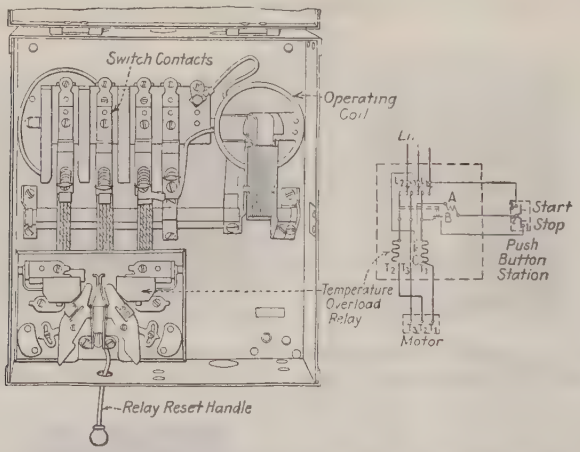
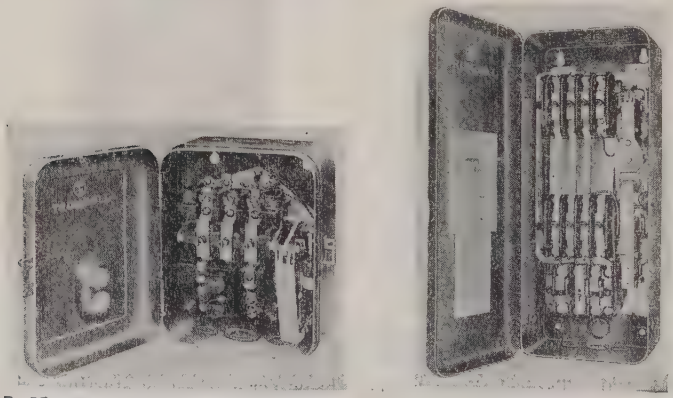


FIG. 131.—Magnetic across-the-line starter. (*General Electric Co.*)



I. Non-reversing type with push button in cover.

II. Reversing type.

FIG. 132.—Magnetic across-the-line starters for polyphase squirrel-cage motors. (*Trumbull Electric & Manufacturing Co.*)

281. Magnetic, across-the-line starting switches consist of a magnetically operated switch controlled from a push-button station. They are provided usually with thermal-relay overload and undervoltage protection. In the switch shown in Fig. 131 pressing the start button closes the circuit of the operating coil *A* of the magnetic switch. This allows a

current to flow from L_1 to 3, through the start button to 2, through the operating coil, and back to L_3. The operating coil, being energized, closes the magnetic switch. The switch in closing also closes the auxiliary contact B so that when the start button is released the operating coil is still energized through the circuit L_1, 1, 2, A, C, L_3. To stop the motor the stop button is pressed. This opens the circuit of the operating coil, allowing the switch to open. In case of an overload the thermal relays expand and open contact C. This de-energizes the operating coil A and allows the switch to open. If the voltage of the line fails or falls to a low value, the operating coil will not be energized sufficiently to hold the contacts of the switch closed. As the switch opens, the contacts B are opened, so the motor will not start upon return of normal voltage until the start button is pressed.

Magnetic, across-the-line starting switches are made in a variety of types for both nonreversing and reversing duty. The reversing types consist of two magnetic switches electrically interlocked so as to prevent the closing of both switches at the same time (Fig. 132, *II*).

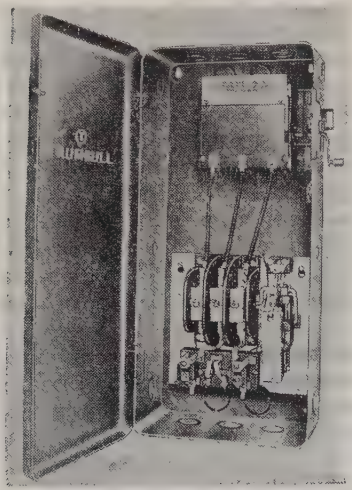


FIG. 133.—Magnetic starter with no-fuse motor-circuit switch. (*Trumbull Electric & Manufacturing Co.*)

FIG. 134.—Magnetic starter with fused motor-circuit switch. (*Trumbull Electric & Manufacturing Co.*)

282. Combination Magnetic Across-the-line Starters.—Magnetic across-the-line starters can be purchased which include in the same metal enclosure other branch-motor-circuit protective and switching equipment. The following different combinations are available as standard equipment:

1. Magnetic starter and no-fuse, motor-circuit switch (Fig. 133).
2. Magnetic starter and fused motor-circuit switch (Fig. 134).
3. Magnetic starter and time-limit circuit breaker (Fig. 135).

The National Electrical Code rules require the installation of a motor-circuit switch on the line side of each magnetic starter. These combinations make a very compact and neat installation for the fulfillment of these requirements. Almost any desired combination can be obtained for either nonreversing or reversing service. It is very often desirable to include in the enclosure a set of test jacks so that meters may be easily plugged into the motor circuit for analysis of voltage, current, and power conditions.

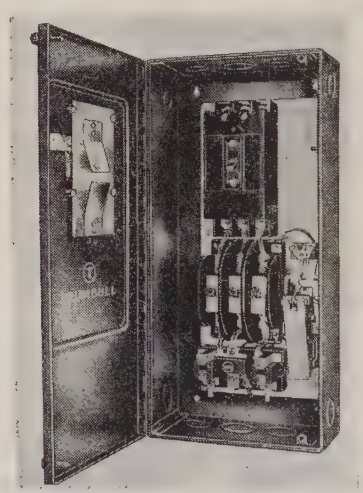


FIG. 135.—Magnetic starter with time-limit circuit breaker. (*Trumbull Electric & Manufacturing Co.*)

283. Safety-enclosed circuit breakers (see Div. 4) of the magnetic-overload-trip type may be employed for across-the-line starters for polyphase induction motors. Breakers used for this purpose should be equipped with overload protection of the inverse-time-lag type. Such breakers will fulfill the functions of starter, motor-overload protective device, and motor-circuit switch. Two circuit breakers mechanically interlocked so that both breakers could not be closed simultaneously could be employed for reversing service.

284. Commercial compensators or autostarters consist of an autotransformer, a double-throw switching device, and overload and undervoltage protective devices, all compactly mounted in a sheet-metal case. They can be obtained for either manual or magnetic operation. The manual type is provided with a lever outside the case which controls the double-throw-switch mechanism. When the handle is in the "off" position the motor and autotransformer are both disconnected from the line. Throwing the lever to the "start" position connects the autotransformer to the line and the motor to the secondary taps of the autotransformer applying the reduced voltage for starting. When the handle is thrown to the "run" position, the motor is connected directly to the line, and the autotransformer is entirely disconnected from the circuit. The switching mechanism is so designed that it cannot be left in the "start" position but will automatically return to the "off" position, unless thrown to the "run" position after the start.

Most manual compensators are provided with a "stop" button so interconnected with the overload protective device that, if pressed, the button will actuate the device and open the compensator contacts.

In the automatic compensator the same sequence of operations as in the hand-operated type is performed automatically after the operator has pressed the starting button. The acceleration may be time-limit or current-limit controlled. Most automatic compensator starters employ

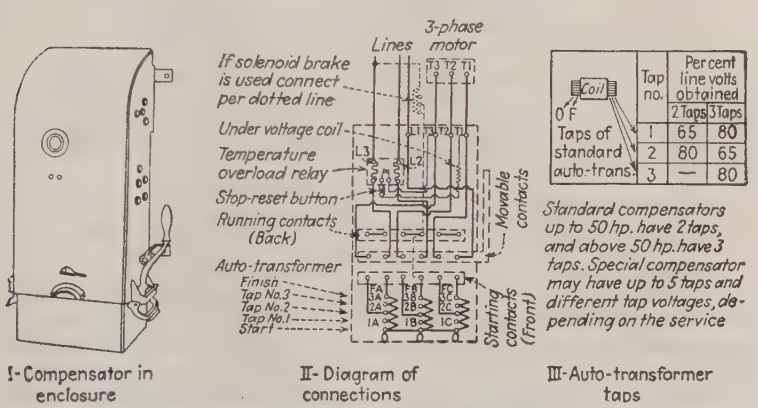


FIG. 136.—Manual compensator for squirrel-cage motor. (*General Electric Co.*)

the time-limit method. The closing of the start button closes the operating coil of a magnetic contactor which connects the motor to the line through the autotransformer. With time-limit control after a sufficient time has elapsed, a definite-time relay closes its contacts, completing the operating circuit of a second magnetic contactor. The closing of this second contactor disconnects the autotransformer from the circuit and throws the motor directly across the line. With current-limit control, a current-limit relay closes the operating-coil circuit of the second contactor after the current has been reduced to the proper value.

In order to stop the motor it is simply necessary to depress the stop button, which opens the operating coil of the magnetic contactor, allowing the contacts to open and disconnect the motor from the line.

Compensators are provided with two or more sets of secondary taps on the autotransformers so that the voltage best suited to the required starting conditions may be used. Typical compensators are shown in Figs. 136 to 142.

The standard compensator does not provide for reversing duty. For such service an additional reversing switch of either the manual or magnetic type would be required.

285. Overload protection on autotransformer starters is provided by means of thermal or magnetic relays. In manual compensators the overload relay opens the holding-coil circuit, allowing the switch of the

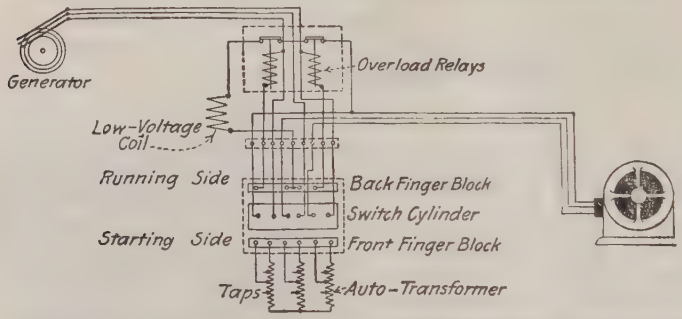


FIG. 137.—Overload protection provided by relays on a three-phase starting compensator.

compensator to return to the "off" position. In magnetic compensators the overload relay breaks the circuit of the operating coil of the magnetic contactor so that the contactor opens.

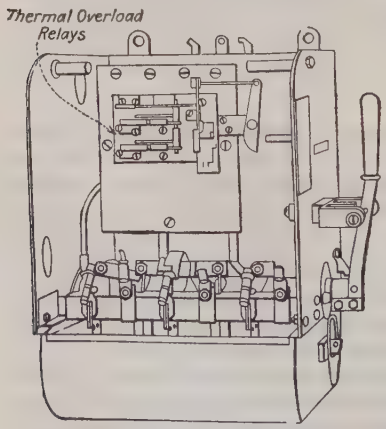


FIG. 138.—Autostarter with cover removed showing thermal overload relay. (*Westinghouse Electric & Manufacturing Co.*)

Typical connections for overload protection with thermal relays are shown in Fig. 136 and those for magnetic relays in Fig. 141. The relays generally are arranged so that they can be adjusted to operate at different currents. Thermal relays inherently have inverse-time characteristics. When magnetic relays are employed, they generally are equipped with devices to give the inverse-time feature. An inside view of an autostarter showing a thermal overload relay is reproduced in Fig. 138. The overload relays of compensators used for high-voltage motors are isolated from the high-voltage circuit by means of current transformers, as shown in Fig. 139.

286. Undervoltage protection is almost always provided on autotransformer starters.—For manual compensators the holding coil of the compensator switch acts as the undervoltage coil (see Figs. 136 and 139). The holding coil is connected across the line when the switch is in the

running position. If the voltage of the line drops sufficiently the coil is de-energized to such an extent that the switch is released and returned to its "off" position by its spring. For magnetic compensators the oper-

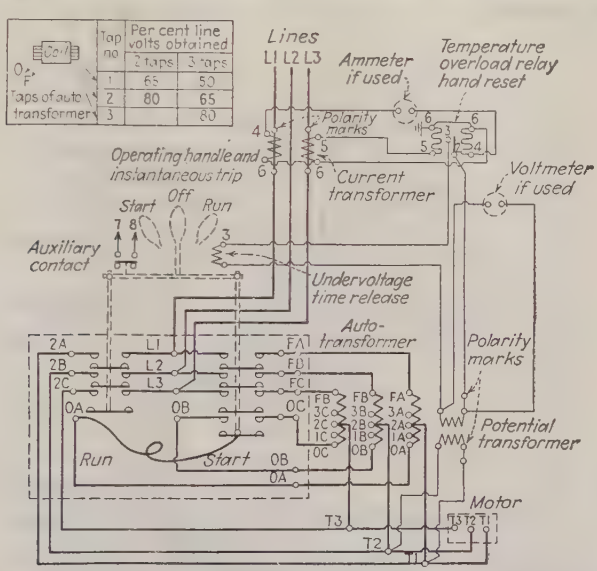
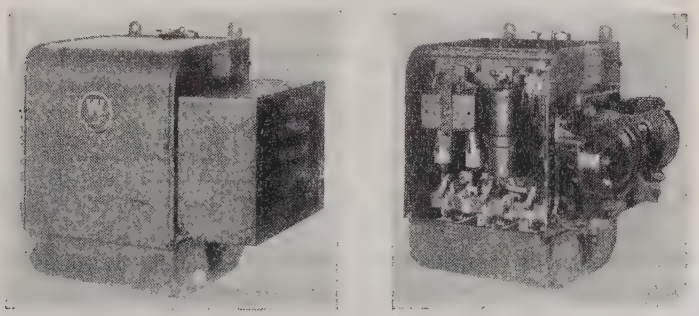


FIG. 139.—Manual-compensator diagram for high-voltage squirrel-cage motor. (*General Electric Co.*)



I. Compensator in enclosure II. With cover removed

FIG. 140.—Magnetic compensator for squirrel-cage motor. (*Westinghouse Electric & Manufacturing Co.*)

ating coil of the running contactor acts as the undervoltage coil (see Fig. 141). If the voltage of the line drops sufficiently, this operating coil is de-energized to such an extent that it cannot hold the running contactor

closed. The holding or operating coils of compensators for high-voltage motors are energized from the secondary of a small-voltage transformer, as shown in Fig. 139. The secondary voltage of these transformers is generally 110 volts.

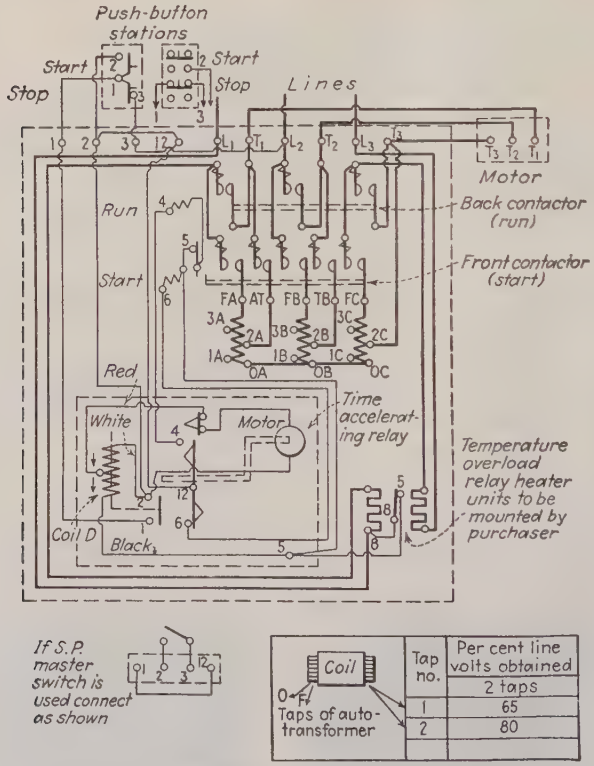


FIG. 141.—Diagram of connections for a magnetic compensator. (*General Electric Co.*)

287. A magnetic compensator is shown in Fig. 140. It consists of a running contactor, a starting contactor, autotransformer, accelerating relay, and an overload relay. In the compensator illustrated, acceleration is time controlled. This is the more usual method of automatically controlling acceleration, but current control is also employed. The compensator of Fig. 141 functions as follows. When the start button is pressed, a circuit is closed from L_2, through the stop and start buttons, to 2, to 12, through accelerating relay contact to 6, through operating coil of starting contactor to 5, through overload relay contacts to 8, and back

to L_1. The operating coil of the starting contactor is thus energized, and the starting contactor closes, applying reduced voltage to the motor through the autotransformer. At the same time a circuit is closed from L_2, through stop and start buttons to 2, through the motor of the accelerating relay to 5, through overload relay to 8, and back to L_1. Current through coil D closes contact 1–2 and allows current to flow from L_2 through stop button to 1, through contact 1–2 to 12, through 12–6 to operating coil of starting contactor, and back to L_1, even though the start button is opened. After a certain definite time the timing motor opens contacts 12–6 and closes contacts 12–4. The opening of contacts

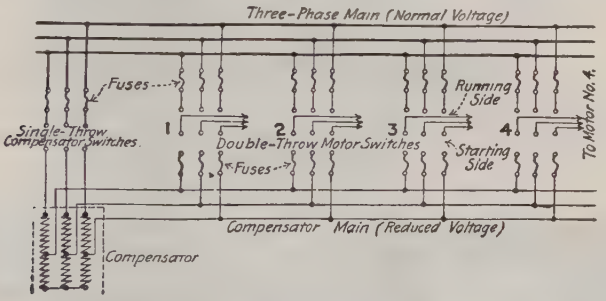
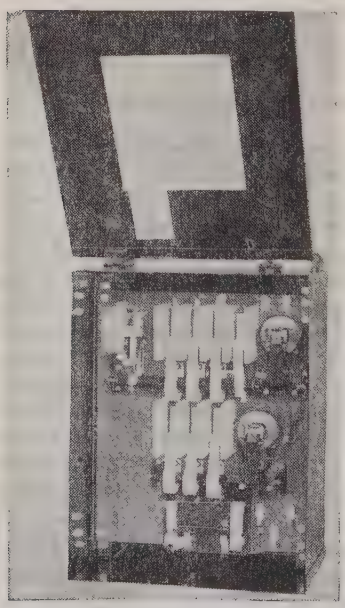


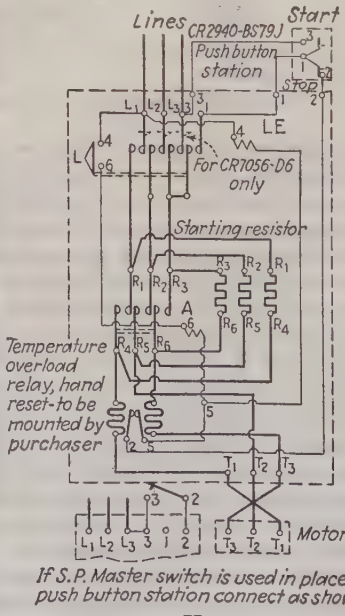
FIG. 142.—Starting several motors from one compensator.

12–6 breaks the circuit of the operating coil of the starting contactor, allowing the contactor to open, and closes contact 5. The closing of contacts 12–4 and 5 allows current to flow from L_2 through the stop button to 1, through contact 1–2 to 12, through contact 12–4, through the operating coil of the run contactor, through contact 5, through the overload relay to 8, and back to L_1. The operating coil of the running contactor is thus energized, and this contactor closes, applying full voltage to the motor. Opening the overload relay or pressing the stop button will open the circuit of coil D. This de-energizing of D will allow contact 1–2 to open, which breaks the circuit to the operating coil of the running contactor, allowing this contactor to open and disconnect the motor from the line.

288. A method of starting several polyphase induction motors from one compensator is shown in Fig. 142. This can frequently be employed to advantage where there are a number of motors situated close together or where a number of motors must be started from one location. A double-throw switch is necessary for each motor to be started, and there should be a switch for the compensator. If all the starting switches are located close together, so that one operator can open or close them consecutively, the compensator need have a capacity only sufficient for serving the largest motor in the group. If the starting switches are so located that several can be operated at once by different men, the com-

FIG. 143.—Primary resistance starter of the dial type for squirrel-cage motor. (*General Electric Co.*)





I II

FIG. 144.—Magnetic primary-resistance starter for squirrel-cage motor. (*General Electric Co.*)

pensator must have a sufficient margin of capacity to provide for this. After all the motors are started, the compensator switch is opened, eliminating compensator losses.

289. Commercial primary-resistance starters for squirrel-cage induction motors are made in both manual and magnetic types. The magnetic types generally provide time-limit acceleration. They are similar to the starters for d-c motors except that they are provided with resistors

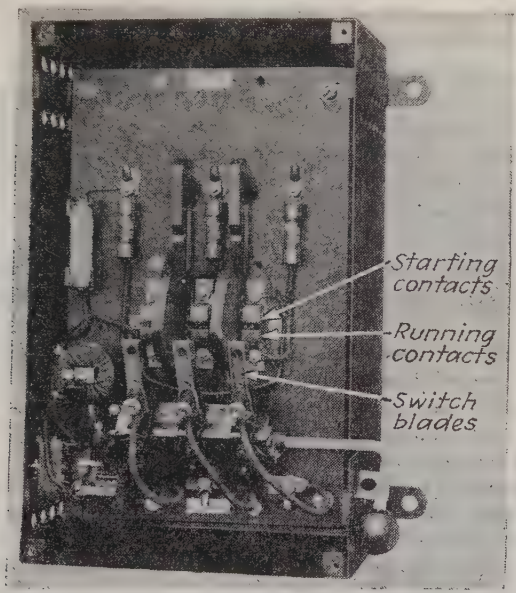


FIG. 145.—Two-position-switch type ofp rimary-resistor starter for squirrel-cage motor. (*Cutler-Hammer.*)

and switching equipment for each phase, all phases being switched simultaneously. In some types the resistance is all cut out in one step, while in others the starting resistance is cut out in several steps. The manual starters may be of the dial or drum type. A dial type of primary-resistance starter for a two-phase motor is shown in Fig. 143. With the manual starters, overload and undervoltage (if desired) protection must be provided separately from the starter in the same manner as discussed in Sec. **257.** A magnetic starter is shown in Fig. 144. Magnetic starters are provided with overload protection and either undervoltage protection or release as desired. Primary-resistance starters of the drum and magnetic types may be obtained for reversing or nonreversing service.

When manual control is employed and one step of starting resistance is satisfactory, a two-position-switch type of starter (Fig. 145) is some-

times used. Throwing the operating lever as far as it will go in the closed position connects the motor to the line in series with the starting resistance. The overload protective fuses are cut out of the circuit in this position, and the operaing arm of the switch must be held in by hand. When the arm is released, a spring moves it partially down, closing the main running contacts. In the "run" position the resistance is cut out, and the protective fuses are inserted in the circuit.

290. Control apparatus for multispeed, squirrel-cage induction motors are made in the following types:

1. Across-the-line starters.
   a. Mechanically interlocked manual switches or circuit breakers.
   b. Drum switches.
   c. Electrically interlocked magnetic contactors.
2. Primary-resistor, reduced-voltage starters.
   a. Drum switches.
   b. Magnetic.

The fundamental principles and general construction of these starters are similar to starters of the corresponding types for single-speed, squirrel-cage motors, except that they must provide means for making the necessary changes in the connections of the stator winding for different speeds. Where separate switches are employed for the different connections, provision should be made for mechanically or electrically interlocking the switches. Otherwise the switches for different speeds might accidentally be closed at the same time and cause a short circuit.

291. Starters for Automatic-start Induction Motors.—The starters for automatic-start induction motors of the normal-construction type may consist of any one of the types of across-the-line starters as described in preceding sections for single-speed, polyphase, squirrel-cage induction motors. Automatic-start induction motors of the special construction described in Sec. **164** are started with magnetic starters. These starters consist of a primary contactor, a secondary contactor, thermal overload relays, and a timing relay mounted in a common enclosure. When the push-button or the automatic control is actuated, the primary magnetic contactor closes immediately, connecting the line to the motor. The secondary magnetic contactor is still open, the low-resistance winding is open-circuited, and the high-resistance, short-circuited winding limits the starting current and produces a correspondingly high starting torque. The motor commences to turn and comes quickly up to speed, and after a certain time interval the secondary magnetic contactor closes, short-circuiting the low-resistance winding. The motor then operates with low slip and temperature rise and with good efficiency, until it is shut down by the operation of the push-button or automatic control, when the magnetic contactors open and the motor is ready for another start. The timing relay is adjustable over a wide range, and its operation is not affected by temperature or age.

292. Controllers for wound-rotor motors are manufactured in dial, drum, and magnetic types. The same piece of equipment is utilized for both starting and speed control, when speed control is desired. The same precautions must be taken in using a controller for speed control, however, as are outlined in Sec. **266** for armature speed controllers for d-c motors.

293. Dial controllers for wound-rotor motors are similar to dial controllers for d-c motors, except that they have two or three sets of resistances controlled by means of two or three contact arms (Fig. 146)

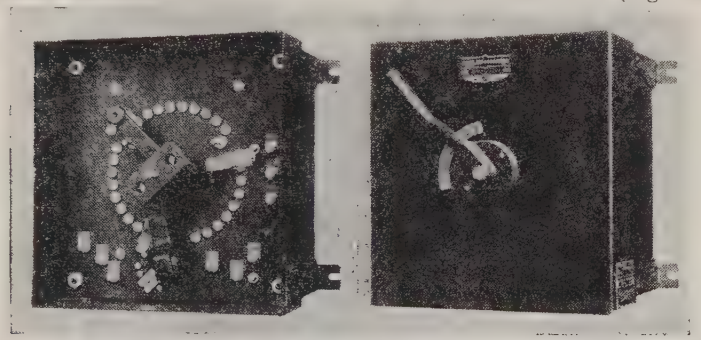


FIG. 146.—Dial type of starter or speed regulator for wound-rotor motor. (*Cutler-Hammer.*)

These controllers control the resistance in the rotor circuit only, so a separate switch and overload protection must be provided in the stator circuit. It is best to have this primary line switch of the magnetic type (Fig. 147) so that it can be electrically interlocked with the secondary controller. With such an arrangement the motor cannot be started unless the resistance is cut into the rotor circuit. The connections of a wound-rotor motor with such a controller are shown in Fig. 147*A*. For reversing service a reversing switch is provided in the stator circuit.

294. Drum controllers for wound-rotor motors are similar in appearance and general construction to those employed for d-c motors (see Fig. 115), except that the movable contacts control two or three sets of resistances instead of only one set. In addition to those contacts for controlling the rotor resistance, some drum controllers are provided with contacts for opening and closing the stator circuit. If the drum is not so designed, it is best to have the line switch of the magnetic type so interlocked with the secondary controller that the line switch cannot be closed, unless the resistance is cut into the rotor circuit (Fig. 148).

Controllers of this type are suitable for nonreversing or reversing service. Overload protection and undervoltage protection, if desired, must be provided in the stator circuit.

295. Magnetic controllers for wound-rotor induction motors consist of a primary contactor and one or more secondary contactors, depending

upon the number of steps of secondary resistance employed. They may be obtained for reversing or nonreversing duty. Reversing starters require two electrically interlocked primary contactors. Time acceleration is employed for most of these controllers, but current-limit or frequency-limit is used for some applications. A typical magnetic controller for a wound-rotor motor is shown in Fig. 149.

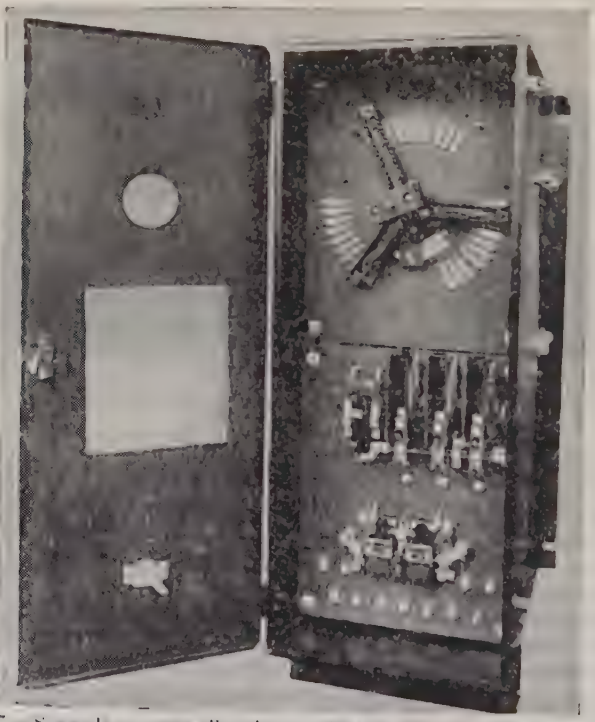


FIG. 147. Secondary controller in combination with magnetic primary switch. (*Cutler-Hammer.*)

A multicircuit-escapement-type timing relay controls the sequence and time of operation of the successive contactors. A controller using frequency control of acceleration is shown in Fig. 149.1.

296. The starting equipment for the commutator type of polyphase induction motor generally consists simply of some type of across-the-line starter, as described in Secs. **277** to **282.** In the special cases where resistance is connected in series with the secondary for starting, the control would be similar to that employed for wound-rotor motors. The

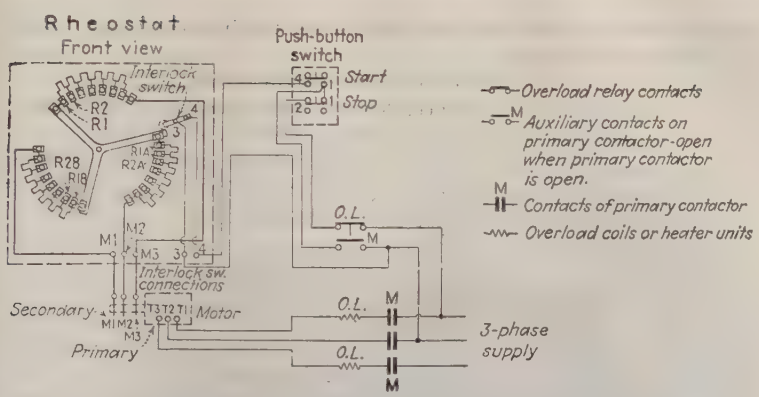


FIG. 147A.—Diagram of connections for dial-type secondary controller with primary magnetic switch interlocked with secondary controller.

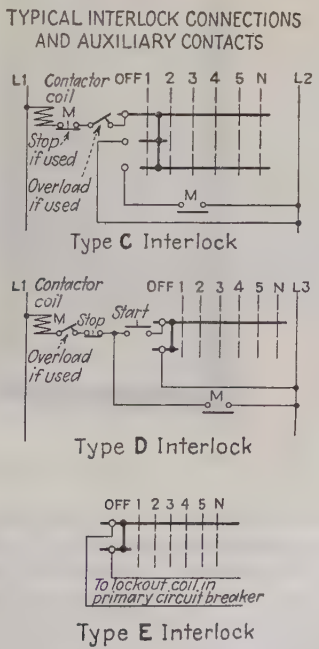


FIG. 148.—Drum controller for secondary control of wound-rotor motors. (*Cutler-Hammer.*)

speed control may be regulated by shifting the brushes in any one of the following three ways:

1. By means of a handwheel mounted on the motor.
2. By means of a handwheel located conveniently for the operator and connected to the brush-operating shaft by a chain drive.
3. By means of a pilot motor and reduction-gear mechanism which is mounted on the main motor frame and controlled by push buttons located at the most convenient point for the operator.

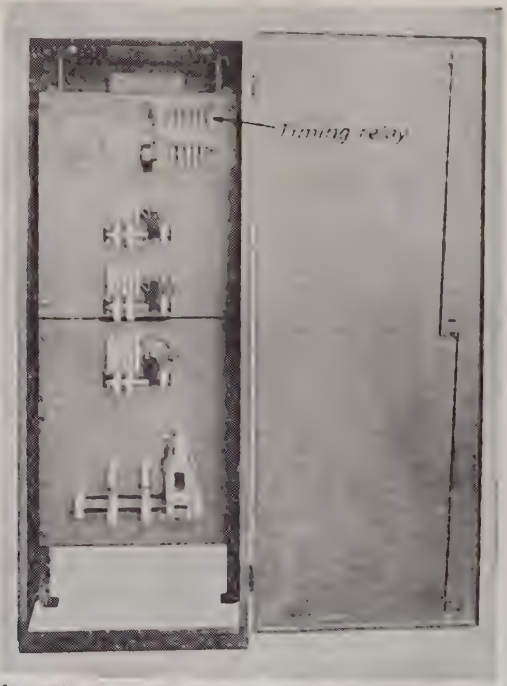


FIG. 149.—Magnetic controller for wound-rotor motor using time-limit control. (*General Electric Co.*)

Typical connections for a magnetic controller used when motor speed is hand adjusted are shown in Fig. 150. The operating coil of the contactor is connected in series with a limit switch on the motor so that the contactor will not operate unless the brushes are adjusted to the low-speed position. When a secondary resistor is employed for special starting conditions or for obtaining creeping speeds, a magnetic controller is always employed. This controller will consist of a primary contactor electrically interlocked with a secondary contactor.

297. Starters for polyspeed induction motors consist of some form of across-the-line starter as previously described for single-speed, polyphase, squirrel-cage induction motors.

298. The control equipment for synchronous motors of conventional design is the same as that for squirrel-cage induction motors with the addition of the necessary field-control equipment. The control equipment is usually of either a semiautomatic or full-automatic type. The semiautomatic type for reduced-voltage transformer starting (Fig. 150*A*) consists of a standard manual compensator, a field-actuating relay and contactor, a field rheostat, and overload and undervoltage protective devices. When the starter is in the "off" position the field circuit is short-circuited through a proper value of resistance. The throwing of the handle of the compensator to the "start" position connects the motor to the line through the low-voltage taps of the compensator, leaving the field short-circuited. When the handle is thrown to the "run" position, the motor is connected directly to the full line voltage, and the field-actuating relay is energized. When the motor has reached approximately synchronous speed, or after a definite time, the relay operates and energizes the field contactor which applies excitation to the motor field.

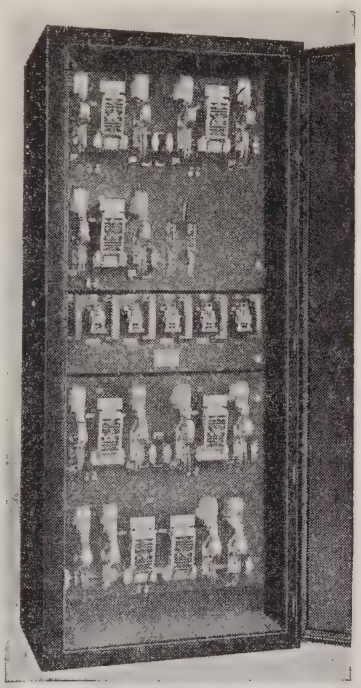


FIG. 149*A*.—Magnetic controller for wound-rotor motor using frequency control of acceleration. (*Electric Controller & Manufacturing Co.*)

The essential parts of a full-automatic controller for reduced-voltage transformer starting are a line contactor, an accelerating contactor, a definite-time relay, a field-actuating relay and contactor, an autotransformer, a field rheostat, and overload and undervoltage protective devices. When the controller is in the "off" position the field circuit is short-circuited through the proper value of resistance. Pushing the start button energizes the accelerating contactor, which connects the autotransformer to the line and the motor to the secondary taps of the autotransformer. At the same time the definite-time relay is energized. After the definite-time interval, which corresponds to the setting

of the definite-time relay, the accelerating contactor opens and the line contactor closes. The opening of the accelerating contactor disconnects the autotransformer from the line and disconnects the motor from the autotransformer. The closing of the line contactor connects the motor directly to the line and energizes the field-actuating relay. When the motor reaches approximately synchronous speed, the field relay closes and energizes the field contactor, which closes and applies excitation to the field circuit.

An automatic starter for full-voltage starting of synchronous motors (Fig. 151) consists of a line contactor, a field-actuating relay and con-

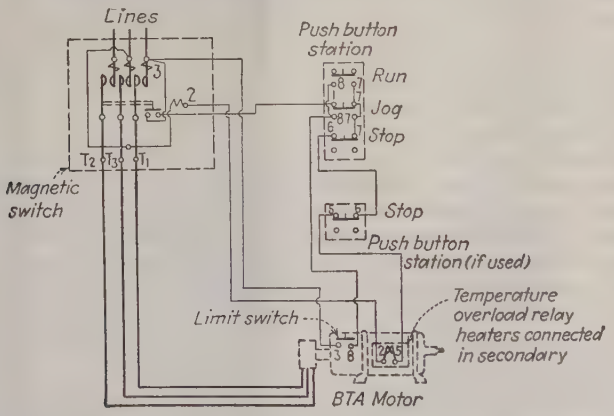


FIG. 150.—Diagram of connections for control of commutator-type polyphase induction motor when using hand adjustment of speed. (*General Electric Co.*)

tactor, a field rheostat, and overload and undervoltage protective devices. Pushing the start button energizes the line contactor and connects the motor directly across the line with the field short-circuited through the proper value of resistance. When the motor reaches nearly synchronous speed, the contacts of the field-actuating relay automatically close. At a definite time after this the field contactor closes, applying excitation to the field circuit.

Resistance starters for synchronous motors of conventional design are generally fully automatic. They are similar to primary-resistance starters for squirrel-cage induction motors with, as mentioned above, the necessary relays and contactors for field control.

A saturable-reactor type of controller is employed sometimes for very large motors, when a large number of starting steps are required. The principle of this method of acceleration is illustrated in Fig. 151*A*. Each phase is supplied with a saturable reactor, which is built on a three-

leg iron core. Coils on the outside legs of the reactors are connected in series with the motor, and coils on the middle leg are connected to a source of direct current in series with a rheostat. In starting the motor the d-c coils are at first disconnected from their supply. The reactor then has a high impedance to alternating current and limits the first inrush of current. The d-c coils are then energized with all the resistance of their control rheostat cut into the circuit. The current in the d-c coils decreases the impedance of the a-c coils. As the rheostat cuts resistance out of the d-c circuit, the direct current increases still further, reducing the impedance of the a-c coils until the reactor core is saturated and the impedance of the a-c coils is practically zero. A large number of steps is thus easily available for starting the motor. An actual controller would generally be automatically operated and would include field-control equipment for the motor.

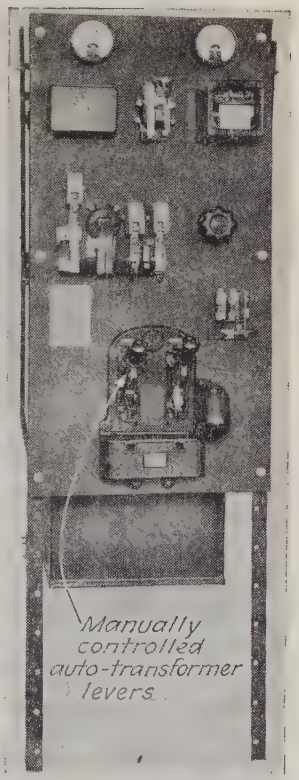


FIG. 150*A*.—Reduced-voltage semiautomatic starter for low-voltage synchronous motor. (*Westinghouse Electric & Manufacturing Co.*)

299. The control equipment for synchronous motors with wound-rotor secondaries will generally consist of a full-automatic magnetic controller of the same general type as used for wound-rotor induction motors with the addition of relays and contactors for field control.

300. The control equipment for Fynn-Weichsel motors may be of either the manual or the automatic type. The manual controllers are usually of the face plate type for motors of sizes up to 20 hp. and of the drum type for motors of 25 hp. and larger. The starting equipment and its operation whether of the manual or the automatic type are practically identical with the corresponding type of equipment used with wound-rotor induction motors.

301. Control Equipment for Single-phase Motors.—Single-phase motors are almost always started by throwing directly across the line. Some type of across-the-line starter similar to those discussed in Secs. **277** to **282** for polyphase motors is employed. Some of the manual types with thermal overload protection are frequently called secondary

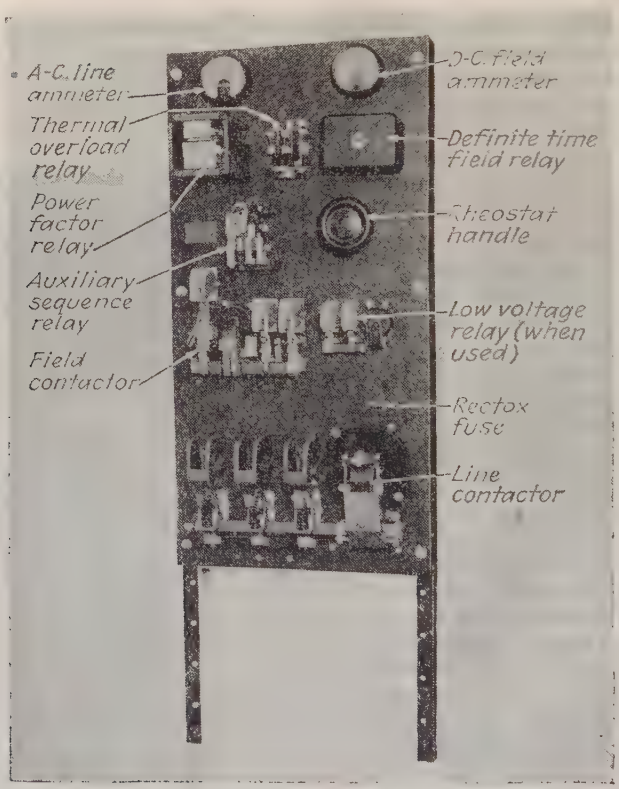


FIG. 151.—Full-voltage full-automatic starting panel for low-voltage synchronous motor. (*Westinghouse Electric & Manufacturing Co.*)

breakers. They are not really circuit breakers, for they are not designed for interrupting short circuits.

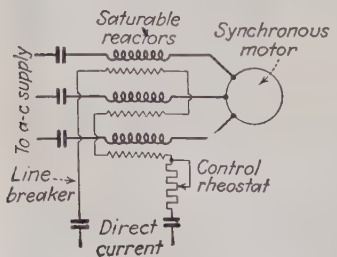


FIG. 151*A*.—Connections for starting synchronous motor with saturable reactors.

A hand-closing, magnetic-contactor type of starting switch is made by one manufacturer (Fig. 151*B*). It consists of a magnetic contactor which must be manually closed, but when closed has its operating coil energized, thus keeping the circuit closed until it is opened by hand or because of undervoltage. Most of the manual across-the-line starters do not provide undervoltage protection.

When the starting current of the larger sizes is greater than allowable, a dial or drum starting rheostat similar to those for d-c motors is generally employed.

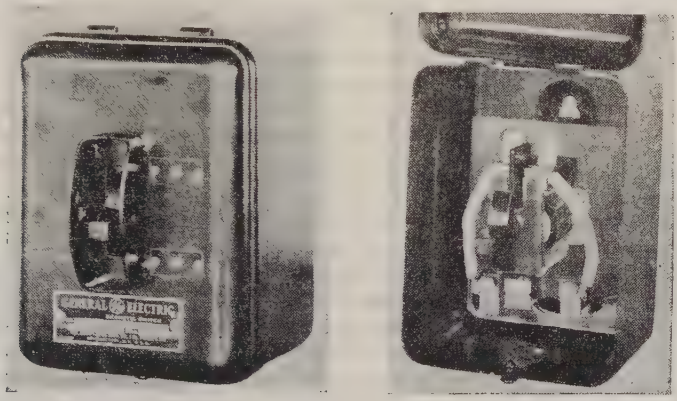


FIG. 151*B*.—Hand-closing magnetic-contactor starting switch. (*General Electric Co.*)

MOTOR DRIVES AND APPLICATION

302. Design of Motor Drives.—The proper design of motor drives for machines is a very important problem. It involves not only the selection of a type and rating of motor but also selection of a method of connecting the motor to the driven machine and selection of control equipment. It is affected by power supply, driven-machine requirements, space limitations, safety and working conditions for operators, initial cost and operating costs, production and quality of product, and surrounding conditions. The objective is to obtain a final installation which will be the best when all considerations are taken into account. The manner of attacking and the complexity of the solution of the problem depends upon the particular case. In some cases the limitations are so definitely fixed that they dictate only one answer. For instance, a machine requires a speed of 1,600 r.p.m. and a full-load power of 24 hp. with a very occasional peak of 28 hp. and an average load of 20 hp. It is not necessary to maintain an absolutely fixed ratio of speed between driving and driven shaft. No speed control is required, but the speed should not vary more than 10 per cent with load changes. The starting-torque requirements are very light, but the power company will allow only exceptionally low starting currents. The power supply is 60 cycles, 220 volts, three phase. The machine is operated in a dry and clean location with normal temperatures. In this case there is no difficulty in making the proper selection. A normal-torque, normal-starting-current, 25-hp., four-pole, 220-volt, three-phase, 1,800-r.p.m., open squirrel-cage induction motor with

reduced-voltage starting equipment would be used. The motor would be belt connected to the machine.

In many cases the problem is not so simple and it cannot be split up into several simple isolated problems that can be answered individually, such as selection of type and rating of motor, method of connection, etc. The selection of the type of motor and the method of connection are interdependent so that the whole problem must be considered as a unit, carefully weighing all factors involved. Generally several different plans may be used. Each one should be worked out with respect to intial cost, operating costs, and maintenance; then the possible solutions should be weighed against each other, taking into account, in addition to the above costs, the effect of the proposed drives upon safety and working conditions of operators, and upon production and quality of product.

It is evident that in order to design proper motor-drive installations it is necessary to have a knowledge of the different methods of mechanical connections and of their advantages and limitations and all the other important factors that will affect the correct selection of motors. In the following paragraphs the important points that must be considered in the selection of motors and mechanical connections are discussed, followed by tables which, it is believed, will be helpful guides to proper selection. In the latter part of this division under Installation of Motors and Generators is given the procedure for the design of the different types of drives.

303. Methods of Driving Machines.—There are two methods that may be employed for driving the individual machines of a shop. Each machine may be equipped with its own individual motor. This is called individual drive. In other cases a single motor may be employed to drive a group of machines by means of shafting and belts. This is called group drive. There are no hard and fast rules that can be made favoring one method over the other for every application. Each case should be decided on its own merits through a careful consideration of the advantages and disadvantages of each method for that particular installation.

The factors to be considered in making the selection are: initial cost, operating cost, production, working conditions, quality of product, nature of work, and nature of construction of the building. A discussion of these factors is reproduced in the following sections through the courtesy of the General Electric Company.

304. Initial Cost of Drive.—There is no doubt that considerable saving in the initial cost of the motor equipment can usually be made with group drive. For sizes below 5 hp., the cost per horsepower is greater than for the larger sizes. In general, a saving in investment will be realized with group drive:

1. Where there are compact groups of constant-speed machines which will be required to run continuously or simultaneously

2. With compact groups of machines which, because of their diversity factor in operation, may be driven by a single motor of much smaller

rating than the combined capacities of the motors required for individual drive. That is, it is seldom that all machines in a group will be fully loaded at the same time, and a motor capable of carrying the average load of the group may therefore be selected, its overload capacity being sufficient to care for any short-time overload conditions.

3. With groups of constant-speed machines, where heavy peak-load demands might require individual motors of a size considerably in excess of the average running load.

4. When the motors required for individual drive are small.

5. In changing over existing installations, where the line shafting is already installed.

Under certain conditions, however, the initial cost will usually be less with individual drive:

1. Where machines are isolated, requiring long lines of shafting to combine with other groups, so that the cost of the transmission more than offsets the extra expense of individual motors.

2. Where the roof construction will not safely support line shafting, or where the additional expense of making it sufficiently strong would be too great. Occasionally, it is possible to mount the line shafting on the ceiling of the room below and drive up through the floor. The holes cut through the floor to accomplish this purpose weaken the floor and increase the fire hazard so that this scheme is inadvisable; while on the first floor, with no basement underneath, it is impossible.

305. Operating Cost of Drive.—Unless carefully maintained, the transmission equipment will decrease in efficiency on account of gradual misalignment of shafts, increased belt slippage, etc. These losses may be offset, in part at least, by the fact that the efficiency of a motor of large size used with group drive is better than that of the small-sized motors used with individual drive.

There may be a power saving in favor of group drive:

1. In shops where a maximum-demand charge is made, based on the horsepower of the connected load.

2. Where the efficiency and power factor (if there is a power-factor penalty clause) are high because of a nearer approach to full-load conditions.

This point is usually overstressed, as there are many plants equipped with individual drive with a power factor of around 80 per cent, while, in many plants with group drive, the power factor, is low. In lining up machines for group drive, the assumption is automatically made that each of the machines will be operated most of the time, although probably not at capacity. There are many times, however, when possibly only two or three machines out of a group of six or eight are actually operating simultaneously.

There would be a power saving in favor of individual drive:

1. Where many machines operate intermittently or at infrequent intervals.

2. Where much overtime work involving only a few machines is carried on.

3. Where long lines of shafting cause large transmission losses which can be eliminated by substitution of individual drive.

306. Production as Affected by Drive.—In many installations it is possible to increase production with individual motorized drive:

1. By the use of individual magnetic control, whereby the workmen may remain in position to observe the progress of the work and, at the same time, have full control over the driving equipment.

2. Where it is desired to obtain elaborate or specialized control, which may be expensive, cumbersome, or inefficient to accomplish by mechanical means. A good example of such a condition is in printing-press drive.

3. By closer regulation of speed, through elimination of belt slip. Every successive belt through which power is transmitted in group drive usually results in a drop in speed. In laying out installations, reasonable allowance is made for this slip, but, unless considerable attention is paid to maintenance of shaft alignment, belt tension, and load conditions, machines will frequently be found running under speed after being in operation any considerable length of time.

4. Where some considerable portion of the time is required in setup work, taking advantage of the more flexible control possible with an individually motorized equipment.

5. Through less wholesale interruptions due to breakdowns. Many times, with individual drive, production may be temporarily diverted to other machines; with group drive, several machines are affected.

6. Where arranging machines in line for line-shaft drive does not allow a logical arrangement of machines for production purposes. This is particularly important where a rearrangement of the machines is necessary from time to time to keep step with changing conditions.

7. Where the size of the work is such that it is easier, or necessary, to use portable tools. In these cases the tool is moved to the work, and a number of setups and changes in position of a large casting are avoided.

8. By using certain special tools and motors particularly designed for specialized work. The high-speed motors used in woodworking and grinding machinery are very good examples of this. Belt speeds in excess of 6,000 ft. per min. would often be necessary, which would result in very unsatisfactory operation. The combination of a fairly large amount of power per spindle and a very high speed is met here by individually motorized spindles, as well as by individually motorized machines.

307. Working Conditions as Affected by Drive.—It is generally admitted that working conditions are inherently better with individual drive than with group drive.

1. There is less danger, particularly for the maintenance men, from belting, shafting, etc.

2. The psychological effect of working near rapidly moving belts and pulleys is unquestionably bad and has a tendency to increase fatigue, with consequent harmful effect on precision work.

3. Better light and circulation of air are obtained. Lighting conditions are particularly important where artificial light is required, and overhead belting and shafting practically preclude the shadowless lighting so necessary to safety and to accurate work.

4. There is no danger of belts working from loose to tight pulleys, causing unexpected starting of machines.

5. In many cases, manipulation of the driven machine can be made safer for the operator. Good examples are emergency stop stations, located at important points about a machine where hazardous operations are performed; "safety-first" switches which may be locked in the "off" position, preventing their operation by unauthorized persons.

308. Quality of Product as Affected by Drive.—The effect of overhead shafting and rapidly moving belts and pulleys on precision work is discussed above under Working Conditions.

There are other ways in which individual drive aids toward a product of better quality.

1. Where the more precise speed maintenance results in a more uniform product (as in some textile, most grinding, and many woodworking operations).

2. Where the product requires conditions of exceptional cleanliness, which are difficult to obtain with overhead shafting and belts.

309. Miscellaneous Considerations in Selecting Type of Drive.—Under some circumstances, the use of group drive is almost automatically ruled out by the construction of the building or the nature of the work. Such conditions are found:

1. In plants where fairly heavy work is done, requiring clear overhead space for traveling cranes. The convenience, and often the necessity, of this moving material will offset any advantages group drive may otherwise have.

2. Where machines are installed under galleries where there is not sufficient overhead room for line shafting.

3. Where automatic or remote control of a machine is desired, for example, control for a pressure tank or sump pump.

4. In plants where periodic tests are made on each machine to determine the amount of power being used. With individual drive and jack-type switches, such tests may be made without stopping a single machine; with group drive, a shutdown of all machines in the group would be necessary before completing the test.

310. Summary of Factors Affecting Choice of Drive.—In general, it may be said that any compact group of machines which may be equipped with a motor of considerably smaller capacity than the combined capacities of the motors required for individual drive should be considered for

group drive; any machine operating at a fairly constant load, not much below its maximum, should be equipped with individual drive.

The cost of maintenance will be little different as between the two methods. Whatever is saved on motor maintenance with group drive because of fewer and possibly more accessible motors is likely to be used up in maintaining and inspecting line-shaft bearings, belts, pulleys, clutches, etc.

All power costs, including fixed charges, rarely make up more than 3 or 4 per cent of the cost of the finished product. Therefore, any savings along these lines, although not to be overlooked, are not relatively so important as some of the other factors.

The question of production is far more important. Any means whereby production can be increased, by speeding up the process, conserving the workmen's time, locating machines for improved sequence of operation, or making handling of the material easier, will in practically every instance overrule all other factors.

311. Motors may be mechanically connected to machines in several ways. When the speed of the motor is the same as the speed desired for the machine, direct coupling of the motor shaft to the machine shaft is used. When the speed of the motor is different from the speed of the machine shaft, a connection must be used which will give the proper speed ratio between the motor and the machine. A speed ratio may be secured by using a flat belt, V belts, a chain, or a set of gears. With belts the speed ratio is inversely proportional to the effective diameter of the two pulleys. With chain or gears the speed ratio is inversely proportional to the number of teeth on the two sprockets or gears. In some cases a variation in speed may be obtained by using variable-diameter pulleys or more than one set of gears, which can be shifted.

312. The factors to be considered in selecting the method of connection of the motor to the machine are the speed ratio desired, the peak loads to be transmitted, the positiveness of the drive, the space required, the noise, the maintenance, the appearance, and the first cost of the motor and the method of connection. Since the horsepower of a motor is given by the following formula,

$$\text{Hp.} = \frac{6.28 \times \text{r.p.m.} \times T}{33{,}000} \text{ (See Sec. 100, Div. 1)}$$

it follows that for a given horsepower, if the speed of the motor is increased, the torque needed is decreased. To produce torque in a motor costs money for windings to create the necessary magnetic flux and for steel to provide a path for the flux. Therefore, the smaller the torque and consequently the higher the speed the cheaper will be the motor. For very high speeds, however, the extra strength which must be built into the rotor to enable it to withstand the high centrifugal force more than offsets the saving due to the lower torque required.

The 1,800-r.p.m. motor is usually the cheapest motor, higher speed

motors being more expensive on account of the higher centrifugal force and lower speed motors being more expensive on account of the greater flux and torque required. Therefore, one of the first factors to consider in the selection of the mechanical connection of the motor to the machine is to see if an 1,800-r.p.m. motor can be used. The speed of the shaft on the machine to which the motor is to be connected varies with the type of machine and is frequently much lower than 1,800 r.p.m. For example, on forging machines using large flywheels the shaft speed may be as low as 50 to 60 r.p.m.; on machine tools, such as lathes, drills, millers, etc. it may be between 200 and 300 r.p.m. Speeds as high as 1,000 to 2,000 r.p.m. occur on grinders and woodworking machines. In most cases, therefore, some reduction in speed is required between the motor and the machine. Direct connection of the motor to the machine shaft with a flexible or rigid coupling can be used only where the speed of the shaft can be the same as the speed of the motor. Belts, gears, or chains must be used in all other cases to effect a change of speed between the motor and the shaft.

For a speed of 1,200 r.p.m., a 1,200-r.p.m. motor directly coupled to the shaft will usually be more practical than an 1,800-r.p.m. motor with a belt, gear, or chain connection to the 1,200-r.p.m. shaft. For speeds between 600 and 13 r.p.m., gear motors may be used. These motors have a rotor speed of 1,800 r.p.m. and gears built into the end frame of the motor to give the output shaft speed desired. These motors cost about twice as much as a high-speed motor with belt drive but are frequently used on account of the saving in space and elimination of troublesome belts. They are available in three classes of construction, according to the severity of service (see Sec. **125**).

313. Belt drive is the least expensive method of connection where speed ratio is required. The factors to be considered when applying a belt drive are speed ratio, pulley sizes, belt speeds, distance between pulley centers, type of belt, size of belt, number of belts, number of pulleys, use of idler pulleys, and slippage. The maximum speed ratio which can be obtained with belt drive is limited by the practical sizes of pulleys obtainable, the arc of contact of the belt on the smaller pulley, and the practical distance between the pulleys. The maximum practical speed ratio may be as high as 10:1 for fractional horsepower motors but is about 6:1 for ordinary sizes and not more than 4:1 for motors of 50 hp. and up. As the diameter of a motor pulley is reduced the strains on the motor bearings and shaft are increased. A minimum size of pulley is therefore specified by N.E.M.A., as given in Sec. **394A.** The maximum diameter of motor pulley is in nearly all cases limited by the belt speed, which should not exceed 5,000 ft. per min. This will occur only for machines which operate at a higher speed than the motor. Flat belts are slightly cheaper than V belts but have a shorter life and are more noisy and more dangerous. Flat belts with a high speed ratio usually require idler pulleys, and space must be available for the idler

pulley when required. There is always some slippage between the belt and the pulleys, and a belt drive should be used only where a positive drive is not required.

314. Maximum Horsepower Limits for Two-bearing Motors for Belt Drive (General Electric Company)

Motor speed, r.p.m.	Flat-belt drive, max. hp.	V-belt drive, max. hp.	Motor speed, r.p.m.	Flat-belt drive, max. hp.	V-belt drive, max. hp.
1,700–1,800	40	60; ball-brg, 75	680–720	200	300
1,440–1,500	40	60; ball-brg, 75	560–600	200	300
1,150–1,200	75	100; ball-brg, 125	500–514	150	300
850– 900	125	200	440–450	150	250

315. Chain drive is a more positive drive than belt drive, and, although it is more expensive than belt drive, it is used where slippage under varying loads is not desired. The factors to be considered when applying a chain drive are: speed ratio, the size of sprockets, width of chain, chain speed, and noise. The maximum speed ratio for a chain drive is about 8 :1 with a maximum chain speed of 1,500 ft. per min. For quietness and smoothness a speed of 600 ft. per min. or less is desirable. A chain drive is more noisy than belt drive.

316. Maximum Horsepower Limits for Two-bearing Motors for Chain Drive (General Electric Company)

Motor speed, r.p.m.	Max. hp.	Motor speed, r.p.m.	Max. hp.	Motor speed, r.p.m.	Max. hp.
1,700–1,800	5	1,150–1,200	25	720–750	75
1,440–1,500	10	850– 900	50		

317. Gear drive is an absolutely positive drive but is the most expensive method of connection. The factors to be considered when applying a gear drive are: speed ratio, gear sizes, pitch-line speed, space, and noise. The maximum speed ratio is about 10 :1 for a single set of gears, but any speed ratio is obtainable by using several sets of gears. Where the pinion of ordinary spur gearing is mounted on the motor shaft, two-bearing motors should be limited to the maximum horsepower values given for chain drive in Sec. **316.** The maximum pitch-line speed with steel pinions is about 1,300 ft. per min. Gear drive usually is compact and takes up only a small space but is more noisy than the other methods. It should be used on any application where slippage or breaking of the belt or chain would be seriously dangerous. It can also be used for much larger speed ratios than are practical with belts or gears.

318. Comparison of Methods of Connection for Adjustable-speed Drive

Type of motor	Type of drive	Space required	Speed variation ratio	First cost
Constant speed.....	Variable pitch motor pulley	Same as V-belt connection	1¼:1	Low
Constant speed.....	Separate unit with variable-diameter pulleys	Considerable	3½:1	Medium
Constant speed.....	Variable-diameter pulley unit built on motor housing	Moderate	3½:1	Medium
Constant speed.....	Variable-position rollers	Small	10:1	High
Adjustable speed.....	Direct coupling	Small	4:1	High

319. Comparison of Methods of Connection for Constant-speed Drive

Type of drive	Relative noise	Space required	Speed ratio obtainable	Peak load transmitted	First cost
1. Direct coupling, standard motor.	0	Small; motor must extend out from end of drive shaft	0	Limited only by motor	1 (considered as 100 per cent)
2. Direct coupling, general-purpose gear motor.	Slight	Same as 1. Angle drive obtainable in small motors	Any	Full load	2 times the standard motor
3. Direct coupling, special-purpose gear motor.	Slight	Same as 2	Any	150 per cent of full load	2½ times the standard motor
4. Direct coupling, heavy-duty gear motor.	Slight	Same as 2	Any	200 per cent of full load	3 times the standard motor
5. V belt.....	0	Moderate	10 : 1 in fractional-horsepower sizes; down to 4 : 1 for 50 hp. and up	Any by multiplying motor horsepower by a service factor[1]	1⅓ times the standard motor
6. Flat belt.....	Considerable	Considerable	Same as 5	Same as 5	Slightly higher than for standard motor
7. Chain.....	Considerable	Moderate	8 : 1	Same as 5	1⅓ times the standard motor
8. Gear.....	High	Small	10 : 1, single reduction; 100 : 1, double reduction	Same as 5	1½ times the standard motor

[1] Refer to Sec. 396*D*.

320. The important factors to be considered in selecting a motor are:

1. Power supply.
   a. Type of system—d-c or a-c; frequency; number of phases.
   b. Voltage and frequency conditions.
   c. Effect of motors on power-supply system. *d.* Power rates.
2. Requirements of driven machine.
   a. Speed. *b.* Mechanical arrangement.
   c. Power and torque. *d.* Special conditions.
3. Surrounding conditions.
   a. Ambient temperature. *b.* Atmospheres.
   c. Water. *d.* Altitude. *e.* Quietness.
4. Codes, standards, and ordinances.

A summary of motor characteristics is given in Sec. **337.**

321. The type of power-supply system available in most cases answers the question of whether a-c or d-c motors will be used as well as the frequency of the motors if a-c. For most applications either a-c or d-c motors will be satisfactory. In some cases special requirements of extra-wide speed range, large number of adjustable-speed machines, or severe accelerating or reversing duty may justify the conversion of alternating to direct current.

If a new power plant is to be installed, the operating conditions may sometimes affect the choice of current. Even in this case the characteristics of the new plant generally should agree with those of the nearest central station in order to obtain breakdown service and to operate economically with central-station energy on reduced loads. For certain applications, d-c motors are preferable; for example, in adjustable-speed service, as in machine-tool operation, in service where frequent starts must be made with very high torque, or in reversing service, as in the operation of cranes, hoists, etc. The voltage of a-c circuits can be so readily transformed up or down that such energy is more economical for distribution over considerable areas. For plants extending over a considerable area or distributing energy to distances, say, of ¼ mile or more, alternating current is nearly always more economical.

For a-c motors, three-phase, 60 cycles is most desirable except for small fractional-horsepower motors. The demand for two-phase motors is small, and they are therefore not generally available in stock for quick shipment. If a multispeed motor is desired where the power supply is two-phase, it is best to transform to three-phase for this machine, as multispeed motors are difficult to wind for two-phase. Standard 60-cycle motors are usually suitable for operation on 50-cycle systems with some modification in their ratings and characteristics. The demand for 40- or 25-cycle motors is so small that they are not generally available in stock. For special high-speed applications in the woodworking industry and for portable tools, motors of higher frequencies than 60 cycles are available

and are sometimes advantageous. The power supply can be obtained by means of an induction frequency changer.

322. The conditions of the supply voltage and frequency, if alternating current, with respect to value and regulation must be known in order to select the proper motors and control. With a-c systems the voltage can, of course, be changed through transformers wherever it is advisable. Table 323 gives a guide for good practice in the maximum and minimum horsepower limits for the different standard motor voltages.

Motors will operate successfully under some conditions of voltage and frequency variations but not necessarily in accordance with the standards established for operation at normal rating (see Sec. **130**).

Where the variations in voltage and frequency exceed those limits, special motors and control will probably be required.

The voltage regulation of the supply should be known in order to select motors which will deliver sufficient torque, even with the probable drop in voltage, to start and carry the load. All induction-motor torques and synchronous-motor starting torque and pull-in torque vary as the voltage squared.

The speed of a-c motors will be affected by the frequency of the supply voltage as discussed in previous sections for each type of motor.

323. Guide to Horsepower Limits of Individual Motors for Different Systems

Voltage	Min. hp.	Max. hp.	Voltage	Min. hp.	Max. hp.
D-c			A-c, two- and three-phase		
115	None	30			
230	None	200	110–115–120	None	15
550–600	½	None	220–230–240	None	200
			440–550	None	500
A-c, one-phase			2,200	40	None
110–115–120	None	1½	4,000	75	None
220–230–240	None	10	6,600	400	None
440–550	5	10			

324. The effects of motors and their control on the power-supply system will affect the selection of the proper type of motor.

The effect of motor-starting currents upon the supply and permissible limits for starting currents are discussed in Sec. **132.**

With fluctuating loads, care should be taken to see that the following limits are not exceeded:

1. Frequencies of current pulsation in the range of 250 to 600 per minute may cause objectionable light flicker even if the voltage variation is as small as ½ of 1 per cent.

2. The usual limit for current pulsation is 66 per cent of motor full-load current, although in some cases the sytem regulation may require a limit of 30 or 40 per cent to avoid light flicker.

325. Effect of Power Rates on Motor Selection.—When speed adjustment is required, the energy charge in the power rates should be considered in the selection of the type of motor and in making selection between mechanical adjustable-speed drive and an adjustable-speed motor.

The power rates are generally based on the maximum demand of the consumers. The choice of motor and use of flywheels may smooth out the power demand. This will keep the maximum demand down and lower the rate.

A power-factor clause is incorporated in many rate schedules. These adjust the rate according to the power factor of the load or involve a penalty or bonus for power factors that are below or above certain values. In such cases, consideration should be given to the use of synchronous motors or power capacitors.

326. Effect of Speed Requirements on Motor Selection.—Since there is a great difference in the speed characteristics of different types of motors, the maximum allowable speed regulation (variation in speed with load) on the driven machine is an important factor in the selection of the proper motor. The actual operating speed, number of speeds, or the speed range required are factors which must be considered in the joint selection of type of motor and mechanical connection. See Secs. **311** to **319** for description and comparison of different methods of mechanical connection. Where speed control of the driven machine is required, it may be obtained through speed control of a motor of the proper type or by means of a motor coupled to the machine through a mechanical speed-adjusting connection.

Close speed regulation is desirable for many applications such as machine tools, textile machinery, and similar work.

Where large peak loads occur, wide speed regulation is desirable. This will allow the motor to slow down under the peak loads and reduce the horsepower carried at these moments. If the motor has a small speed regulation it may be greatly overloaded at the peak loads unless the machine is equipped with an exceptionally large motor.

For peak loads occurring periodically, where the peaks occur less than 25 times per minute, flywheels should be employed with motors having a wide speed regulation. This will allow the use of a smaller motor and will tend to even out the peaks of power drawn from the supply.

327. Mechanical-arrangement features of the driven machine should be taken into account in motor selection. The General Electric Company makes the following recommendations:

1. Horizontal or Vertical Shaft.—Arrangement of the driven machine usually determines whether a horizontal or vertical motor is needed. Horizontal motors are more generally available and less expensive; most grease-lubricated, ball-bearing motors will operate in either position. Fractional-horsepower, waste-packed, sleeve-bearing motors

are satisfactory for short periods of vertical operation where no thrust is involved.

2. Tilted Shaft.—If momentary, this will require special construction of bearing housings for oil-ring-lubricated, sleeve-bearing motors, to avoid loss of lubricant. In case of long periods of tilted operation, bearings suitable for end thrust may be necessary. Ball-bearing motors with grease lubrication are suitable for tilted operation.

3. Inverted Operation and Rolling.—*a.* Where the driven machine requires mounting the motor with the feet above or to one side of the shaft, rearrangement of the end shields of most motors makes them suitable.

b. If the driven machine requires operation of the motor at a changing angle from the horizontal (shaft remaining horizontal) of more than 10 or 12 deg., ball-bearing motors will usually be required. Within this angle, sleeve-bearing motors with modified oil gages are applicable.

4. Portable Machines.—A portable type of driven machine may require motors and control of greater compactness and less weight than standard and may necessitate special bearing construction for ring-oiled, sleeve-bearing motors.

328. The horsepower and torque requirements of the driven machine are main factors in determining the proper motor rating, type of motor, and motor-control equipment. The greatest care should be exercised in determining as accurately as possible the horsepower required and both the starting- and running-torque requirements. The motor must not only have sufficient horsepower and torque capacity under running conditions but must be able to develop sufficient torque at starting in order to start the load satisfactorily under the most severe starting conditions that may be encountered in that particular application. Sometimes all these requirements will be known from past experience. In all cases, where it is possible, it is best to conduct tests so that the power and torque requirements can be accurately determined. Money spent in such determinations is wisely expended even if it requires the rental of a motor for conducting the tests. In performing tests it should be remembered that the test-motor losses must be subtracted from the power input to the motor, since the motor to be purchased is rated on horsepower output.

If the power and torque requirements cannot be determined from past experience or test, the information can generally be obtained from the manufacturer of the machine to be driven or from the motor experts of motor manufacturers. Wherever there seems to be any question with respect to the accuracy of such information, it should be carefully checked, since the machine-tool manufacturers often overestimate the horsepower required so as to be on the safe side. The result is that the motors run only partially loaded at considerably reduced efficiency. The electrical losses and interest and depreciation on the unnecessary

extra investment may be a considerable amount in a large installation.

Whenever the frequency of the starting periods is great, more than four to six times per hour, it is best to consult the motor manufacturers. Such frequent starting may require special motors and control.

329. Horsepower Rating of Motor.—After having determined the horsepower requirements of the load, select a motor with sufficient horsepower rating to take care of these requirements. See Sec. **130** for discussion of motor ratings.

330. Any special conditions of operation of the driven machine must be carefully considered. Some machines such as propeller-type fans and deep-well pumps impose an axial thrust on the motor bearings. In some cases standard ball-bearing motors will furnish sufficient thrust capacity. For extremely heavy thrusts, special plate-type, oil-lubricated bearings may be required.

For some tools such as precision grinders, in order to ensure high quality of the finished product, specially balanced motors are required in order to give very small amplitudes of vibration.

Sometimes the driven machine requires limited or even zero end play. This will necessitate the use of preloaded ball bearings or sleeve bearings with end-play-limiting devices.

331. The surrounding conditions of temperature, atmospheres, and water must be carefully determined in the application of motors. Refer to Sec. **128** for a discussion of the different standard types of enclosures available and a guide to the surrounding conditions under which their applications will be satisfactory. For a discussion of rating of motors and effect of room temperatures upon operation, refer to Sec. **130.** When the motor and control will be subjected to any unusual risk such as those listed below, the manufacturers should be consulted.

Unusual Risks

1. Exposed to chemical fumes. 2. Operated in damp places.
3. Operated at speeds in excess of specified overspeed.
4. Exposed to combustible or explosive dust.
5. Exposed to gritty or conducting dust. 6. Exposed to lint.
7. Exposed to steam. 8. Operated in poorly ventilated rooms.
9. Operated in pits or where entirely enclosed in boxes.
10. Exposed to inflammable or explosive gases.
11. Exposed to temperatures above 40°C. or below 10°C.
12. Exposed to oil vapor. 13. Exposed to salt air.
14. Exposed to abnormal shock or vibration from external sources.

332. Water (General Electric Company).—Where operation for long periods under water is required, special enclosed equipment, with counter air pressure to prevent the entrance of water, is usually necessary.

For occasional flooding or submersion, extremely tight totally enclosed nonventilated motors equipped with stuffing boxes may suffice.

Where "hosing down" or splashing of water is involved, splashproof

motors will usually meet all but extreme conditions, the latter requiring enclosed motors.

333. Altitude (General Electric Company).—No change in design is considered necessary for most electric machines for altitudes not exceeding 3,300 ft. above sea level. For higher altitudes, the temperature rise of electric machinery generally will increase approximately 1 per cent for each 330 ft. increase in altitude above 3,300 ft.

334. Quietness (General Electric Company).—Installations in residences and in public buildings, such as theaters, hospitals, and schools, may require the use of quiet motors and sound-isolating bases. In many cases, special building layout and construction may be needed to ensure the necessary degree of quietness.

335. Codes, Standards, Ordinances (General Electric Company).—Motors and control must conform to local and national standards such as shown below in order to (*a*) permit connection of power, (*b*) satisfy safety and fire requirements, and (*c*) permit lowest insurance rates.

1. N.E.M.A. standards, which specify mounting dimensions for induction motors and, in general, minimum performance characteristics for all types of motors and control.

2. A.I.E.E. standards, which specify temperature limits for insulation materials and prescribe the methods of rating and testing apparatus.

3. The National Electrical Code, which is the general guide of inspectors in determining acceptability of enclosures, protection, and installation of motors.

4. State laws, which stress safety and reduction of fire hazards.

5. City ordinances, which may specify particular construction considered necessary locally to avoid fires and accidents.

336. Standard Ratings of Motors.—The standard horsepower ratings of motors are $\frac{1}{20}$, $\frac{1}{12}$, $\frac{1}{8}$, $\frac{1}{6}$, $\frac{1}{4}$, $\frac{1}{3}$, $\frac{1}{2}$, $\frac{3}{4}$, 1, $1\frac{1}{2}$, 2, 3, 5, $7\frac{1}{2}$, 10, 15, 20, 25, 30, 40, 50, 60, 75, 100, 125, 150, 200, 225, 250, 300, 350, 400, 450, 500, 600, 700, 800, 900, 1,000, 1,250, 1,500, 1,750, 2,000, 2,250, 2,500, 3,000, 3,500, 4,000, 4,500, and 5,000 hp.

The standard full-load speed ratings for d-c motors are 3,500, 1,750, 1,150, 850, 690, 575, 500, 450, 400, 350, 300, 250, 200, 150, and 100 r.p.m., except that small motors $\frac{1}{3}$ hp. and less have only two standard speeds of 1,725 and 1,140 r.p.m.

The standard speeds for 60-cycle synchronous motors are 3,600, 1,800, 1,200, 900, 720, 600, 514, 450, 400, 360, 327, 300, 277, 257, 240, 225, 200, 180, 164, 150, 138, 121, 120, 109, 100, 95, 90, 86, and 80 r.p.m.

The standard sychronous speeds for 60-cycle, polyphase induction motors are 3,600, 1,800, 1,200, 900, 720, 600, and 450 r.p.m.

The standard synchronous speeds for 60-cycle, single-phase motors are 1,800, 1,200, and 900 r.p.m.

The approximate full-load speeds of induction motors can be obtained from the synchronous speeds by means of the approximate full-load slips (see Sec. **337**).

337. Summary of Motor Characteristics

Type of motor	Standard hp. ratings	Speed characteristics	Speed control	Locked-rotor starting currents with rated impressed voltage in percentage of full-load current	Starting torque in percentage of full-load rated torque	Max. running torque in percentage of full-load rated torque	General application suited for
1. Direct current, shunt, constant speed	Up to 200	Constant; not more than 10 per cent change in speed from no load to full load	Speed may be increased 25 per cent above normal by field control; speed may be reduced any amount below normal by armature control but speed then varies widely with load	Very high; normally reduced to 150 per cent of rated full-load current by series starting resistance	Maximum with full voltage, 250 to 300; when started in normal manner, average, 150	Would occur at standstill but limited by commutation to 200	Constant- or slightly adjustable-speed service with light or medium starting duty
2. Direct current, shunt, adjustable speed	Up to 200	Nearly constant for any field adjustment, not more than 15 per cent change in speed from no load to full load	Speed range of 4 : 1 for all loads by field control. Speed may be reduced by armature control but speed then varies widely with load	Same as 1	Same as 1	Same as 1	Adjustable-speed service with close speed regulation and either light or medium starting duty. Motors available for either constant-torque or constant-horsepower service
3. Direct current, compound, 20 per cent series, 80 per cent shunt	Up to 200	Slightly varying speed, changes approximately 25 per cent from no load to full load	Same as 1	Same as 1	Maximum with full voltage; 300 to 350; when started in normal manner, —average 170	Would occur at standstill but limited by commutation to 300	Heavy starting duty or intermittent peak-load service or combination of the two duties

compound, 50 per cent series, 50 per cent shunt					voltage, 400; when started in normal manner, average 200	standstill but limited by commutation to 350	duty or heavy running loads for short periods with alternate light load periods; adjustable varying-speed service
5. Direct current series	3 to 200	Varying	Same as 1	Same as 1	Maximum with full voltage, 450; when started in normal manner, 225 to 300	Would occur at standstill but limited by commutation to 400	Heavy intermittent starting duty or heavy running loads for short periods of time adjustable, varying-speed service. Motor should at all times be loaded or under control of operator
6. Polyphase, squirrel cage, normal torque normalstarting current	1/10 to 400	Constant; speed changes approximately 3 to 5 per cent from no load to full load	None	500 to 1,000. May not meet power companies' limitations. Up to 5 hp., generally started with full voltage; above 5 hp., generally started with reduced voltage. Current drawn from line proportional to square of voltage for transformer starting and directly proportional to voltage for resistance starting	Varies with square of voltage applied to motor; 105 to 150 for full voltage	200 to 250	Constant-speed service with no speed control; light-starting-duty service unless it is permissible to start with full voltage
7. Polyphase, squirrel cage, normal torque, low starting current	7½ to 200	Same as 6	None	500 to 550. Within the limitations of most power companies up to and including 30-hp. size. Above 30-hp. size may not be within power companies' limitations. Current depends upon voltage same as for 6	Same as 6	200 to 225	Constant-speed service with no speed control; medium starting duty. Used in place of motor 6 when its use will eliminate employment of reduced-voltage starting

Summary of Motor Characteristics (*Continued*)

Type of motor	Standard hp. ratings	Speed characteristics	Speed control	Locked-rotor starting currents with rated impressed voltage in percentage of full-load current	Starting torque in percentage of full-load rated torque	Max. running torque in percentage of full-load rated torque	General application suited for
8. Polyphase, squirrel cage, high torque, low starting current	1½ to 150	Same as 6	None	Same as 7	Varies with square of voltage applied to motor; 220 to 275 for full voltage	200 to 250	Constant-speed service with no speed control; heavy starting duty if at not too frequent intervals and if starting period is of not too long duration
9. Polyphase, squirrel cage, low torque, low-starting current	40 to 100	Same as 6	None	350 to 550. Within the limitations of most power companies, current depends upon voltage same as for 6	Varies with square of voltage applied to motor; 50 to 100 for full voltage	125 to 175	Constant-speed service with no speed control, light starting duty only
10. Polyphase, squirrel cage, high-resistance rotor, medium slip	½ to 150	Slightly varying speed; speed changes from 7 to 12 per cent from no load to full load	None	400 to 800. Within the limitations of most power companies. Reduced-voltage starting not satisfactory owing to nature of applications	300 to 400	300 to 400. Occurs at standstill	Service with intermittent peak loads, when peak loads occur less than 25 times per minute; heavy starting duty if at not too frequent intervals and if starting period is of not too long duration
11. Polyphase, squirrel cage, high-resistance rotor, high	1 to 50	Medium varying speed; speed changes from 12 to 17 per cent from no load to full load	None	300 to 500. Within the limitations of most power companies. Reduced-voltage starting not satisfactory owing to nature of applications	225 to 250	225 to 400. Occurs at standstill	Frequent heavy starting duty, intermittent loads of not too long duration where varying speed is satisfactory

12. Polyphase, squirrel cage, multi-speed	½ to 125	Multispeed 2, 3, or 4 definite speeds available; speed changes approximately 5 per cent from no load to full load at highest speed and approximately 25 per cent at lowest speed	Speed controlled by changing number of poles of stator winding; maximum of 4 definite speeds; no speed control between steps	These motors may be obtained in any one of the types of items 6, 7, 8, or 9			Adjustable-speed service where 2, 3, or 4 definite speeds will be satisfactory. Whether motor with characteristics of 6, 7, 8, or 9 is selected depends upon requirements of service as given under these types. Available in designs for constant-torque, constant-hp. or variable-torque, variable-hp. service
13. Polyphase, squirrel cage, automatic start	½ to 75	Constant; speed changes from 4 to 6 per cent from no load to full load	None	350 to 375. Within the limitations of practically all power companies	225 to 250. Pull-in torques of from 150 to 200	200 to 250	Constant-speed service with no speed control; heavy starting duty if at not too frequent intervals and if starting period is of not too long duration
14. Polyphase, wound rotor	½ to 1,000	Depends upon the resistance in the rotor circuit; constant (4 to 6 per cent change from no load to full load) with rotor short-circuited; varying with resistance in rotor circuit (greater resistance greater variation in speed from no load to full load)	Speed can be reduced to 50 per cent below normal at full load by resistance in rotor circuit; only small reduction in speed can be obtained at light loads	250 to 300. Within limitations of all power companies	200 to 275	200 to 275	Constant-speed service with no speed control for very heavy or frequent starting duty or where starting period is of long duration (resistance in rotor circuit during starting period only); adjustable varying-speed service; service with peak loads for short periods; different types of service require resistors of different ratings

Summary of Motor Characteristics (*Continued*)

Type of motor	Standard hp. ratings	Speed characteristics	Speed control	Locked-rotor starting currents with rated impressed voltage in percentage of full-load current	Starting torque in percentage of full-load rated torque	Max. running torque in percentage of full-load rated torque	General application suited for
15. Polyphase, commutator type, brush shifting	5 to 50	Adjustable speed; changes from 5 to 25 per cent from no load to full load depending upon speed setting	Speed range of 3:1 by shifting brushes; very low speeds obtained by inserting resistance in secondary	125 to 175. Within limitations of all power companies	140 to 250	140 to 250 at low speeds; 300 to 400 at high speeds	Adjustable-speed service of the constant-torque type; heavy-starting-duty service if at not too frequent intervals and if starting period is of not too long duration
16. Polyphase, polyspeed induction	1 to 7½	Adjustable speed; speed changes approximately 10 per cent from no load to full load at high speed and approximately 40 per cent at low speed	Speed can be controlled from 0 to 150 per cent of synchronous speed in gradual steps by induction regulator in secondary circuit	Depends upon setting of induction regulator; regulator can be set so that current will be within limitations of any power company. Always started with full voltage	Maximum of from 300 to 400 per cent, but this cannot be attained without exceeding the starting-current limitations of many power companies	400 to 450 at high speed. Reduces as speed is decreased depending upon value of secondary bucking voltage	Adjustable-speed service of the constant-torque type; heavy starting duty
17. Synchronous, general purpose, high speed unity power factor	20 to 5,000	Constant; no speed change from no load to full load	None	400 to 800. May not be within limitations of power company. Current depends upon voltage same as for item 6	100 to 125 for full voltage for sizes up to 500 hp.; 80 to 100 for full voltage for sizes above 500 hp. Varies with square of voltage applied to motor.	150 to 175	Constant-speed service with no speed control and light starting duty; fairly steady load; for power-factor correction

18. Synchronous, general purpose, high speed, 80 per cent power factor	20 to 5,000	Same as 17	None	Same as 17	125 to 200 for full voltage for sizes up to 500 hp.; 100 to 150 for full voltage for sizes above 500 hp. Varies with square of voltage applied to motor	200 to 250	Constant-speed service with no speed control where greater power-factor correction is desired than item 17 will provide, or where starting duty is more severe or where peak loads occur. Heavy starting duty if started with full voltage; medium starting duty if started with reduced voltage
19. Synchronous, special purpose, high speed, low torque, low starting current, unity or 80 per cent power factor	20 to 5,000	Same as 17	None	May be designed for starting currents with rated impressed voltage of from 300 to 500 per per cent of full-load current	50 to 100 for full voltage depending upon design; lower values of starting torque correspond to lower values of starting currents. Varies with square of voltage applied to motor	150 to 300 depending upon design	Constant-speed service with no speed control, light starting duty, for power-factor correction. Used in place of 17 in order to limit starting current without reducing voltage
20. Synchronous, special purpose, high speed, high torque, low starting current	20 to 5,000	Same as 17	None	450 to 500 for single-phase wound rotor; 200 to 300 for polyphase wound rotor	150 to 200. Always started with rated voltage applied to motor and external resistance in rotor circuit	150 to 250	Constant-speed service with no speed control for heavy starting duty, for power-factor correction
21. Synchronous, low-speed, engine and compressor types, unity and 80 per cent power factor	20 to 5,000	Same as 17	None	225 to 350 for full voltage. Within limitations of most power companies. Varies with voltage same as 6	40 to 50 for full voltage. Varies with square of applied voltage	140 to 175 for compressor types; 150 to 200 for unity-power-factor-engine type; 200 to 250 for 80 per cent power-factor-engine type	Constant-speed service with no speed control for direct connection to slow-speed machines such as compressors; light starting duty, for power-factor correction

Summary of Motor Characteristics (*Continued*)

Type of motor	Standard hp. ratings	Speed characteristics	Speed control	Locked-rotor starting currents with rated impressed voltage in percentage of full-load current	Starting torque in percentage of full-load rated torque	Max. running torque in percentage of full-load rated torque	General application suited for
22. Synchronous, low speed special service conventional design, unity or 80 per cent power factor	20 to 5,000	Same as 17	None	325 to 700 for full voltage. May not be within limitations of power company. Varies with voltage same as 6	50 to 200 for full voltage depending upon design; lower values of starting torque correspond to lower values of starting current. Varies with square of applied voltage	150 to 250 depending upon design	Constant-speed service with no speed control, light or medium starting duty, for power-factor correction. Used in place of 21 for heavier starting duty
23. Synchronous, low speed, special service, wound rotor, unity or 80 per cent power factor	20 to 5,000	Same as 17	None	450 to 550 for single-phase wound rotor; 265 to 365 for polyphase wound rotor	150 to 200. Always started with rated voltage applied to motor and external resistance in rotor	175 to 250	Constant-speed service with no speed control, heavy starting duty, for power-factor correction
24. Super-synchronous	100 to 5,000	Same as 17	None	Same as 17	200 (not dependent upon voltage applied to motor)	175 to 250	Constant-speed service with no speed control for large machines requiring high starting torque with low starting current, for power-factor correction
25. Fynn-Weichsel	7½ to 200	Same as 17	Reduced speed may be obtained for short periods	Depends upon resistance connected in secondary; 330 for maximum torque; 200 for starting torque of 150 per cent of full load. Always started with rated voltage applied to motor	Maximum of 250. Resistance in secondary generally adjusted to give 150	150 as synchronous motor; 250 as induction motor	Constant-speed service with no speed control or speed control for short periods; suitable for either light or heavy starting duty; used for power-factor correction

25. Single-phase shading-coil type	1/250 to 1/4	Constant; speed changes approximately 6 per cent from no load to full load	None	High, but owing to small size always satisfactory for full-voltage starting	Very low	Approximately 150	Constant-speed service with no speed control; for very light starting duty
27. Single phase, split phase starting (inductive), general purpose	1/50 to 1/2	Constant; speed changes approximately 6 per cent from no load to full load	None	High, but owing to small size will be within limitations of power companies if manufactured so as to meet N.E.M.A. specifications	75 to 175 for full voltage; varies with square of impressed voltage	175 to 225	Constant-speed service with no speed control; for light starting duty
28. Single phase, split-phase starting (inductive) high torque	1/6 to 1/3	Same as 26	None	High; approximately 850; exceeds N.E.M.A. specifications	150 to 275 for full voltage; varies with square of impressed voltage	225 to 350	Constant-speed service with no speed control; for heavy starting duty
29. Single phase, capacitor start, induction run	1/3 to 3/4	Same as 26	None	Lower than 27. Always satisfactory to start with full voltage	275 to 400	200 to 300	Constant-speed service with no speed control; for heavy starting duty
30. Single phase, capacitor start, capacitor run, two-value capacitor, high torque	1/3 to 10	Same as 26	None	Within the limitations of most power companies. Always satisfactory to start smaller sizes with full voltage	275 to 450	200 to 300	Constant-speed service with no speed control for heavy starting duty. Have better power factors than item 29
31. Single phase, capacitor start, capacitor run, single-value capacitor, low torque	1/2 to 10	Same as 26	None	Within the limitations of most power companies; lower than item 30; generally started with full voltage	40 to 60	150 to 200	Constant-speed service with no speed control for light starting duty

Summary of Motor Characteristics (*Continued*)

Type of motor	Standard hp. ratings	Speed characteristics	Speed control	Locked-rotor starting currents with rated impressed voltage in percentage of full-load current	Starting torque in percentage of full-load rated torque	Max. running torque in percentage of full-load rated torque	General application suited for
32. Single phase, multi-speed capacitor	½₂₀ to ½	Practically constant for high speed; varies considerably for lower speeds	Speed control by changing impressed voltage; 2 or 3 definite speeds; no speed control between steps	Always satisfactory to start with full voltage	Approximately 60–75 for highest voltage setting; varies with square of applied voltage	Approximately 175 for highest voltage and speed setting. Varies as square of voltage for other setting	Adjustable-speed service where 2 or 3 definite speeds are satisfactory; very light starting duty; may not be satisfactory for belt drives
33. Single phase, repulsion start, induction run	⅛ to 15	Same as 26	None	200 to 350; in the larger sizes may not be within limitation of power company	300 to 500 for full voltage; varies with square of impressed voltage	175 to 225	Constant-speed service with no speed control for light or heavy starting duty
34. Single phase, repulsion induction	½ to 10	Same as 26	None	Within limitations of most power companies	225 to 300 for full voltage	Occurs at standstill	Constant-speed service with no speed control for either light or heavy starting duty. Will not take care of as heavy starting duty as 33
35. Single phase, repulsion brush shifting	¼ to 3	Varying	Speed range 4:1 for full load. Very little speed control possible at light loads. 3:1 range for 75 per cent load	Within limitations of most power companies	125 to 300 for full voltage	Above 400 for max. speed; decreases with speed reduction	Adjustable varying speed service; heavy starting duty; service with peak loads for short periods
36. Single phase, series, universal for operation on a-c or d-c	½₅₀ to 1	Varying	Speed can be reduced any amount by resistance in series with motor	High, but owing to small size will be within limitations of most power companies. Sizes from ½ to 1 hp. may require reduced voltage	275 to 400 for a-c full voltage; 300 to 500 for d-c full voltage	Would occur at standstill but maximum safe running limited by commutation	Service requiring speed control where large variation in speed with load is not objectionable; heavy starting duty. Must be directly connected to load

338. Guide to Selection of Type of Motor

Load requirements		Types of motors suitable		
Running	Starting	Direct current	Polyphase alternating current	Single-phase alternating current
All classes of loads requiring constant speed with no speed control	Very light starting duty	Shunt, constant-speed type	1. Normal torque, normal starting current, squirrel-cage induction 2. Normal torque, low starting current, squirrel-cage induction 3. Low torque, low starting current, squirrel-cage induction 4. Synchronous, general purpose, high speed 5. Synchronous, special purpose, high speed, low torque 6. Synchronous, low speed, engine compressor, and special service conventional types 7. Fynn-Weichsel	1. Split phase (inductive) 2. Low-torque capacitor 3. Shading coil (only for extremely light starting duty)
	Light starting duty (starting torque not greater than 100 per cent of full-load torque)	Shunt, constant-speed type	1. Normal torque, normal starting current, squirrel-cage induction 2. Normal torque, low starting current, squirrel-cage induction 3. Synchronous general purpose, high speed 4. Synchronous, high speed, special service, low torque 5. Synchronous, low speed, special service, conventional type 6. Fynn-Weichsel	1. Split-phase (inductive) 2. High-torque capacitor or capacitor start induction run

Guide to Selection of Type of Motor (*Continued*)

Load requirements		Types of motors suitable		
Running	Starting	Direct current	Polyphase alternating current	Single-phase alternating current
	Medium starting duty (starting torque from 100 to 150 per cent of full-load torque)	Shunt, constant-speed type	1. Normal torque, low starting current, squirrel-cage induction in sizes up to 30 hp. inclusive 2. High torque, low starting current, squirrel-cage induction 3. Fynn-Weichsel 4. Synchronous, general purpose, high speed 5. Synchronous, special purpose, high speed, high torque 6. Synchronous, low speed, special service, conventional or wound-rotor types 7. Supersynchronous	1. Repulsion induction 2. Repulsion start, induction run 3. High-torque capacitor or capacitor start, induction run
	Heavy starting duty if at not too frequent intervals and if starting period is of not too long duration (starting torque from 150 to 200 per cent of full-load torque)	Shunt, constant-speed type	1. High-torque, low starting-current, squirrel-cage induction in sizes up to 30 hp. incl. 2. Automatic-start induction 3. Wound-rotor induction with resistance in rotor only during starting period 4. Fynn-Weichsel 5. Synchronous, general purpose, high speed 6. Synchronous, special purpose, high speed, high torque 7. Synchronous, low speed, special service, conventional or wound-rotor types 8. Supersynchronous	1. Repulsion induction 2. Repulsion start, induction run 3. High-torque capacitor or capacitor start, induction run

	duty requiring starting torques above 200 per cent of full-load torque or very frequent starting or starting periods of long duration	series field cut-out after starting	starting period 2. Fynn-Weichsel	2. Repulsion start, induction run 3. High-torque capacitor or capacitor start, induction run
All classes of loads requiring adjustable speed with not much change in speed from no load to full load for any speed setting	Light starting duty (starting torque not greater than 100 per cent of full-load torque)	Shunt, adjustable-speed type for either constant-horsepower or constant-torque service	1. Multispeed squirrel-cage induction for either constant horsepower or constant-torque service 2. Commutator, brush-shifting type of induction motor for constant-torque service 3. Polyspeed for constant-torque service	Multispeed capacitor
	Medium starting duty (starting torque from 100 to 150 per cent of full-load torque)	Shunt, adjustable-speed type for either constant-horsepower or constant-torque service	1. Multispeed squirrel-cage induction if it is permissible to start directly across the line for either constant-horsepower or constant-torque service 2. High-torque, multispeed, squirrel-cage induction 3. Commutator, brush-shifting type of induction motor for constant-torque service 4. Polyspeed for constant-torque service	
	Heavy starting duty, if at not too frequent intervals and if starting periods are of not too long duration (starting torque from 150 to 200 per cent of full-load torque)	Shunt, adjustable-speed type for either constant-horsepower or constant-torque service	1. Special high-torque, multispeed, squirrel-cage induction for either constant-horsepower or constant-torque service 2. Commutator, brush-shifting type of induction motor for constant-torque service 3. Polyspeed for constant-torque service	

Guide to Selection of Type of Motor (*Continued*)

Load requirements		Types of motor suitable		
Running	Starting	Direct current	Polyphase alternating current	Single-phase alternating current
	Very heavy starting duty requiring starting torque above 200 per cent of full-load torque, very frequent starting or starting periods of long duration	Compound wound with series field cut out after starting	Commutator, brush-shifting type of induction with resistance in secondary during starting period	
Intermittent peak loads where it is desirable for motor to have slightly varying-speed characteristics in order to prevent excess motor overloads (flywheel machines); peak loads should occur less than 25 times per minute; any service where a slightly varying-speed characteristic is not objectionable or is desirable	Light or heavy starting duty if at not too frequent intervals and if starting periods are of not too long duration	Compound, 20 per cent series, 80 per cent shunt	High-resistance rotor, squirrel-cage induction (medium slip)	
	Very heavy starting duty or starting at very frequent intervals or starting periods of long duration	Compound, 20 per cent series, 80 per cent shunt	1. Wound-rotor induction with some resistance always in rotor circuit 2. High-resistance rotor, squirrel-cage induction (high slip)	
Varying or adjustable varying-speed service; any service where it is desirable or not objectionable to have speed decrease with increasing load; service requiring heavy torque for short periods with some speed control during light loads	Any type of starting duty	1. Compound, 50 per cent series, 50 per cent shunt 2. Series if motor is always under control of operator or if there is no danger of motor losing its load or if motor is protected by an overspeed device	Wound rotor	1. Series 2. Repulsion, brush-shifting type 3. Repulsion

339. Representative Applications of D-c Motors

Shunt		Compound		Series	
Agitators	Printing presses	Balers	Metal drawers	Baling presses	Hoists
Blowers	Pumps	Bending rolls	Punch presses	Bridges	Hydraulic gages
Conveyors	Mixers	Bulldozers	Shears	Cranes	Lorry cars
Fans	Most woodworking machines			Car retarders and pullers	Rotary car dumpers
Line shafts	Most machine tools			Coke-oven machinery	Yard locomotives

340. Representative Applications of Squirrel-cage Induction Motors

Normal-torque, normal-starting-current, and normal-torque, low-starting-current types	High-torque, low-starting current type	Low-torque, low-starting-current type	High-resistance rotor type	Multispeed type
Blowers	Agitators	Blowers	Balers	Centrifugal transformers
Boring mills	Baking machinery	Centrifugal pumps	Bulldozers	Dough mixers
Drilling machines	Candy machinery	Fans	Metal drawing machines	Elevators
Pumps	Conveyors	Motor generators	Punch presses	Feed mechanisms
Line-shaft drive	Crushers		Shears	Ironers
Most woodworking machines	Canning machines		Elevators	Some machine tools
Most machine tools	Elevators		Cranes	Oil-well pumping and pulling
	Grinders		Hoists	Printing presses
	Flour-mill machinery		Dumbwaiters	Pumps and fans
	Milling machines			Tumblers
	Mixers			Stokers
	Pulverizers			Conveyors
	Reciprocating pumps and compressors			
	Refrigerators			
	Revolving screens			

341. Representative Applications of Wound-rotor, Brush-shifting, and Synchronous Motors

Wound rotor	Polyphase brush-shifting, commutator motor	Synchronous motors		
		Ordinary type	Fynn-Weichsel	Supersynchronous
Bascule lift and swing bridges	Aluminum-foil machines	*High speed*	Automatic screw machines	Cement-manufacturing machinery
Cranes	Bakery machinery	Band saws	Beaters	Flour-milling machinery
Coke pushers	Boilerhouse fans	Blowers	Compressors	Paper mills
Hoists	Centrifugal compressors and pumps	Compressors	Fans	Mixers
Hydraulic gates	Cable-stranding machines	Cotton gins	Ice machines	
Lorry cars	Cloth-printing machines	Fans	Marble rubbing beds	
Main roll drives in iron and steel mills	Cotton-mill calenders	Grinding and crushing machinery	Milling machines	
Rotary car dumpers	Linoleum calenders	Jordans and beaters	Paper mills	
Yard locomotives	Paper winders	Metal rolling mills	Plate rolls	
	Printing presses	Mill line shafts	Polishing and grinding machines	
	Reciprocating pumps	Pumps	Pumps	
	Oil-refinery machinery	*Low speed*	Refrigerating machines	
	Some machine tools	Air and gas compressors	Shoemaking machines	
	Some steel-mill main roll drivers	Band-saw mills	Spinning machines	
	Stokers	Jordans	Weaving machines	
	Table drive for plate-glass grinders	Pulp grinders	Wire-cloth weaving machines	
	Tandem drive for textile mills	Refrigerating machinery	Woodworking machinery	
	Tube machines and calenders in rubber-goods factories			

342. Typical Torque Requirements for Synchronous-motor Applications (N.E.M.A. Standards).—The following represent typical starting-, pull-in-, and pull-out-torque requirements of various synchronous-motor applications. In individual cases, lower values may be satisfactory or higher values may be necessary.

Application	Typical torque requirements, per cent		
	Starting	Pull-in[a]	Pull-out
Attrition mills	60	60	175
Ball mills, for rock products	120	100	140
For ore	175	100	175
Banbury mixers	125	100	250
Band mills	150	20	250
Beaters, standard	125	100	150
Breaker	125	100	200
Blowers, centrifugal, inlet or discharge valve closed	30	60	150
Inlet and discharge valves open	30	100	150
Positive-displacement rotary, by-passed	40	30	140
Chippers, empty	60	50	250
Loaded	50	100	250
Compressors, centrifugal, inlet or discharge valve closed	30	60	150
Inlet and discharge valves open	30	100	150
Nash Hytor, unloaded	40	55	140
Reciprocating			
Air and gas	40	20	140
Ammonia (discharge pressure = 100 to 250 lb. per sq. in.)	40	20	140
Carbon dioxide:			
Single cylinder, double acting:			
Piston-rod diameter = 30 per cent of piston diameter	40/55[b]	20	140
Piston-rod diameter = 40 per cent of piston diameter	60/75[b]	20	140
Piston-rod diameter = 50 per cent of piston diameter	85/100[b]	20	140
Piston-rod diameter = 60 per cent of piston diameter	120/135[b]	20	140
Two cylinder, double acting, 90-deg. cranks:			
Piston-rod diameter = 30 per cent of piston diameter	40/45[b]	20	140
Piston-rod diameter = 40 per cent of piston diameter	45/60[b]	20	140
Piston-rod diameter = 50 per cent of piston diameter	65/80[b]	20	140
Piston-rod diameter = 60 per cent of piston diameter	90/105[b]	20	140
Two cylinder, single or double acting:			
180-deg. cranks	40	20	140
Crushers, cone, unloaded	100	100	250
Gyratory, unloaded	100	100	250
Jaw, unloaded	100	100	250
Roll, unloaded	100	100	250
Edgers	30	30	250
Fans, centrifugal (except sintering fans)			
Inlet or discharge valve closed	30	60	150
Inlet and discharge valves open	30	100	150
Centrifugal sintering, inlet gates closed	30	100	150
Propeller or disk type	30	100	150

[a] The pull-in torque of a synchronous motor varies with the flywheel effect (WR^2) of the load.

[b] Lower value for full-voltage starting. Higher value for "increment" starting.

Application	Typical torque requirements, per cent		
	Starting	Pull-in[a]	Pull-out
Generators, electroplating	40	15	140
Standard a-c or d-c, continuous rated	12	8	150
25 per cent overload rating	15	10	200
Grinders, magazine pulp	50	50	140
Three- or four-pocket pulp	30	30	140
Hammer mills, unloaded	150	100	250
Jordans	50	50	150
Line shafts, flour mill	175	100	150
Rubber mill	125	100	250
Plasticators	125	100	175
Pumps, centrifugal, discharge valve closed, high and medium load	30	60	150
Discharge valve open	30	100	150
Reciprocating, started dry	30	30	150
By-passed	40	40	150
Not by-passed (three cylinder)	150	100	150
Screw type, started dry	30	30	140
Primed	30	100	140
Rod mills	175	100	175
Rolling mills:			
Blooming and slabbing mills, three high	35	25	300
Structural and rail roughing mills	35	25	300
Structural and rail finishing mills	40	30	250
Plate mills	35	25	300
Merchant mill trains	60	40	250
Billet, skelp, and sheet bar mills, continuous with lay-shaft drive	40	30	250
Rod mills, continuous with lay-shaft drive	50	40	250
Hot strip mills, continuous, individual drive	25	20	250
Tube-piercing and expanding mills	40	30	250
Tube-rolling mills	40	30	300
Tube-reeling mills	60	40	250
Hot sheet and tin mills	125	100	400
Cold sheet and tin mills	200	150	250
Brass copper roughing mills	50	35	250
Brass copper strip finishing mills	150	125	250
Rubber mills, open-roll type	125	100	250
Saw, band (see Band mills)			
Saws, gang	100	50	150
Trimmer	100	75	150
Screens, paper-mill	50	50	150
Shredders	50	50	250
Tube mills (see Ball mills)			
Vacuum pumps, Jennings Hytor	40	60	140
Nash Hytor	40	55	140
Reciprocating	40	20	140
Wood hogs	60	60	225

[a] The pull-in torque of a synchronous motor varies with the flywheel effect (WR^2) of the load

342A. Synchronous-motor Application Data

(Westinghouse Electric & Manufacturing Co.)

Unusual operating conditions may modify the requirements. For type of motor to produce the required starting torque see Table 177.

Application	Method of connecting motor to load	Starting conditions	Per cent			Remarks
			Starting torque	Pull-in torque	Pull-out torque	
Cement, Rock Products, and Metal Mining						
Ball mills, mining	Coupled to mill pinion	Mills loaded at start	175–200	110–120	175	Full-voltage starting or resistance control for wound-rotor types. Indicating wattmeter on control
Crushers, gyratory	Coupled or belted	Loaded	150–200	100–125	200	Full-voltage starter required. Continuous operation—varying load
Hammer mill	Coupled	Loaded	150	115	250	Full-voltage starting recommended
Jaw	Coupled or belted	Loaded	150–225	100–125	250	Full-voltage starter required. Continuous load extremely irregular with high peaks
Roll	Coupled or belted	Loaded	225	100	225	Full-voltage starter
Bradley-Hercules	Coupled	Unloaded	80	100	175	Full-voltage starting. Continuous load
Hercules mills, cement	Coupled to mill pinion shaft by resilient flexible coupling; good for severe misalignment and vibration	Loaded	150–200	100–110	175	Special full-voltage starting. Liners may be installed under pedestals to provide compensation for mill settling. Motors should be provided with dustproof bearings
Rod mills, mining	Coupled or belted (Lenix drive) to gear	Loaded	200	120	175	Special full-voltage starter required
Tube mills	Coupled by flexible coupling to reducing gear	Loaded	190	120	175	Special full-voltage starter required

Synchronous-motor Application Data (*Continued*)

Application	Method of connecting motor to load	Starting conditions	Per cent			Remarks
			Starting torque	Pull-in torque	Pull-out torque	
		Compressors and Blowers				
Blowers, cycloidal, positive.	Coupled or engine type	Unloaded	40–60	40 60	150	Standard control. Full-voltage starting recommended. Two-speed motors sometimes used
Turbo, high-speed.	Direct connected or step-up gear	Unloaded, discharge closed	40	60	150	Special reduced-voltage starting
Blowing engines reciprocating.	Engine type	Unloaded	40	40–60	150	Standard control. Full-voltage starting recommended
Compressors, air..	Engine type	Unloaded	40	40	150	Standard control. Full-voltage starting recommended. Flywheel effect important
Ammonia and ammonia booster.	High speed, belted; low speed, usually engine type, occasionally coupled	Unloaded by by-pass	40	40	150	Standard control. Full-voltage starting recommended. Flywheel effect important
Freon.....	High speed, belted; low speed, usually engine type, occasionally coupled	Unloaded by by-pass	45	60	150	Standard control. Full-voltage starting recommended. Flywheel effect important
Gas, reciprocating.	High speed, belted; low speed, engine type	Unloaded by by-pass	40	40	150	Standard control except on magnetic control a gastight push button is recommended. Full-voltage starting usually used. Flywheel effect important. Control and exciting equipment usually installed in separate room

Fans						
Exhaust and ventilating.	Coupled or belted	Usually loaded	50	60–125	150	Reduced- or full-voltage starting. WR^2 of fan must be considered
Flour Mills						
Line shaft.....	Coupled or belted	Loaded	175–225	100–125	175	Full-voltage starting required
Lumber						
Band saws and resaws	Coupled or belted	Unloaded. Torques depend on WR^2 of saw	80–125	75–115	200–250	Full-voltage starting. Accelerating time, 45 to 90 sec. Special motor for starting high inertia load
Pulp and Paper						
Jordans.....	Coupled with flexible coupling	Unloaded	50	50	150	Standard control. Full-voltage starting recommended
Beaters.....	Belted	Loaded	125	100	175	Full-voltage starting recommended
Pulp grinders.....	Coupled by flexible coupling	Unloaded	50	50	150	Standard control. Full-voltage type recommended
Wood hogs and chippers.	Coupled or engine type	Unloaded. Torques depend on WR^2 of machine	80–125	80–110	225	Full-voltage starting recommended

Synchronous-motor Application Data *(Continued)*

Application	Method of connecting motor to load	Starting conditions	Per cent			Remarks
			Starting torque	Pull-in torque	Pull-out torque	
			Pumps			
Centrifugal, water, oil, sewage.	Coupled by flexible coupling	Valves either open or closed. Usually closed	Valves open or closed, 35–20	Valves closed, 35–50 valves open, 100–120	150	Standard control, full or reduced voltage
Reciprocating....	Coupled by flexible coupling to pump pinion shaft	Unloaded or by-passed	50–75	25–50	150	Use standard-price-book control. Full-voltage type recommended
Reciprocating, vacuum.	Belted or direct-connected engine type	Unloaded	30–50	60–85	150	Use standard-price-book control. Full-voltage type recommended. Horsepower should be based on peak-load conditions
Rotating vacuum.	Belted or direct-connected engine type	Loaded	40	55–100	150	Standard control. Horsepower should be based on peak-load conditions

Rubber						
Banbury mixers and plasticators.	Direct drive or through reduction gear	Usually unloaded. May reverse under load in emergency	125–150	100–110	250	Special reversing control required. Usually full-voltage starting. Occasionally two-speed motors
Mill lines, rubber.	Low speed, direct coupled; high-speed, coupled to reducing gear	Usually loaded. May reverse under load in emergency	110–150	110–125	175–250	Full-voltage dynamic braking control with or without reversing recommended. Semimagnetic or magnetic reduced voltage may be used in some cases
Steel						
Piercing mills.....	Direct-connected by flexible coupling; sometimes coupled to reducing gears	Unloaded. May be reversed under load in emergency	80–100	50–60	300–350	Special control required. Full-voltage type recommended
Continuous mills; steel rolling, sheet, bar, billet, skelp, strip mills	Direct-connected by flexible coupling usual practice. Sometimes coupled to reducing gear using higher speed motors	Unloaded. May be reversed under load in emergency	50–100	50–100	250–350	Special control required. Full-voltage type recommended
Rod mills.....	Direct-connected by flexible coupling	Unloaded. May reverse under load in emergency	60–100	50–60	225–275	Special control required. Full-voltage type recommended
Sizing and reducing mills.	Direct-connected by flexible coupling; sometimes coupled to reducing gears	Unloaded. May reverse under load in emergency	80–100	50–60	300–350	Special control required. Full-voltage type recommended

343. Motors for Machine Tools.—In the following paragraphs tables are given as a guide in selecting the proper type and size of motor for driving machine tools. The values of motor sizes are average values compiled from information from various manufacturers of machine tools. For very light or very heavy service these figures may be reduced or increased from the values given. The type of motor is designated by a numeral which refers to the numbering employed for the different types of motors in Table 337.

344. Type and Sizes of Motors for Bolt and Nut Machines

Motors 1, 2, 6, 7, or 12

Size of bolt, in.	Hp.			Size of bolt, in.	Hp.	
	Single	Double	Triple		Single	Double
¼–½	1	1½		¾–2½	3	5
¼–1	2	3	5	1–3	5	
½–1½	2	3	5	1½–4	7½	10
½–2	3	5	7½			

345. Type and Sizes of Motor for Boltheading, Upsetting, and Forging Machines

Motors 3, 11, or 14

Size of bolt, in.	Hp.	Size of bolt, in.	Hp.
¾–1½	5– 7½	2½–3	20–25
1½–2	10–15	4 –6	30–40

346. Type and Sizes of Motors for Bolt Pointers

Motors 1, 6, or 7

Size of Bolt, In.	Hp.
1½–2½	1–2

347. Type and Sizes of Motors for Bending and Straightening Rolls

Motors 4 or 14

Width, ft.	Thickness, in.	Hp.	Width, ft.	Thickness, in.	Hp.
4	⅜	5	8	1⅛	35
6	5/16	5	10	1½	50
6	7/16	7½	24	1	50
6	¾	15			

348. Type and Sizes of Motors for Buffing Lathes

Motors 1, 6, or 7

Size of wheel, in.	Hp.	Size of wheel, in.	Hp.
6 × ¾	¼– ½	10	1–2
8 × 1	1 –2	12	2–3
8 × 1½	1 –2	14	3–5

349. Type and Sizes of Motors for Bulldozers

Motors 3, 11, or 14

Width, in.	Head movement, in.	Hp.	Width, in.	Head movement, in.	Hp.
29	14	5	45	18	15
34	16	7½	63	20	20
39	16	10			

350. Type and Sizes of Motors for Cylinder-boring Machine

Motors 1, 2, 6, 7, or 12

Diam. of spindle, in.	Max. boring diam., in.	Hp.
4	20	7½
6	30	10
8	40	15

351. Type and Sizes of Motors for Boring and Turning Mills

Motors 1, 2, 6, 7, or 12

Size	Hp.		Size	Hp.	
	Main	Crossrail		Main	Crossrail
36–44 in.	7½–10		10 ft.	20–35	6
50–53 in.	7½–10		12 ft.	25–40	7½
60 in.	12½	3½	14 ft.	30–40	7½
72 in.	15 –20	4	16 ft.	35–50	10
84 in.	15 –20	4–5	20–25 ft.	50	12½
96 in.	20 –27½	5	30 ft.	50–60	15

352. Type and Sizes of Motors for Radial Drills
Motors 1, 2, 6, 7, or 12

Arm, ft.	Hp.	Arm, ft.	Hp.
2½–3 4 –4½ 5	3 5 –7½ 7½–10	6 8–10	10–15 25–35

353. Type and Sizes of Motors for Sensitive Drills
Motors 1, 2, 6, 7, or 12

Size of drill, in.	Hp.	Size of drill, in.	Hp.
½	½	¾	¾

354. Type and Sizes of Motors for Upright Drills
Motors 1, 2, 6, 7, or 12

Size of drill, in.	Hp.	Size of drill, in.	Hp.
12–22 24–28 30–32	1 2 3	36–40 50–60	5 5–7½

355. Type and Sizes of Motors for Multiple-spindle Drills
Motors 1, 2, 6, 7, or 12

Size of drill, in.	Max. number of spindles	Hp.	Size of drill, in.	Max. number of spindles	Hp.
1/32–¼	12	3 – 5	⅜–1	10	10–15
1/16–½	16	5 – 7½	2	4	7½
3/16–⅝	16	7½–10	2	6	10
¼–¾	10	10	2	8	15

356. Type and Sizes of Motors for Horizontal Boring, Drilling, and Milling Machines

Motors 1, 2, 6, 7, or 12

Size of spindle, in.	Hp per spindle	Size of spindle, in.	Hp. per spindle
2	5	4½	7½–10
3½	5–7½	5½	10 –15

357. Type and Sizes of Motors for Gear Cutters

Motors 1, 2, 6, 7, or 12

Size of gear, in.	Hp.	Size of gear, in.	Hp.
24 × 6	2	60 × 12	5 –7½
36 × 9	2 to 3	72 × 14	7½–10
48 × 10	3 to 5	64 × 20	10 –15
30 × 12	5 to 7½		

358. Type and Sizes of Motors for Cylindrical Grinding Machine

Motors 1, 2, 6, 7, or 12

Diam. of wheel, in.	Length of work, in.	Hp.	Diam. of wheel, in.	Length of work, in.	Hp.
10	24	2	14	36	10–15
10	50	5–7½	14	72	10–15
10	72	5–7½	18	120	10–15
10	96	5–7½	18	144	10–15
10	120	5–7½	18	168	10–15

359. Type and Sizes of Motors for Vertical Surface Grinders

Motors 1, 6, or 7

Diam. of Table, In.	Hp.
8	7½
14	15
30	20

360. Type and Sizes of Motors for Grinding Wheels—Double-end

Motors 1, 6, or 7

Size of wheel, in.	Hp.	Size of wheel, in.	Hp.
5 × ½	¼	18 × 3	5 – 7½
6 × ⅜	¼	24 × 4	7½–10
8 × 1	½	26 × 4	7½–10
10 × 1	1	30 × 4	15 –20
12 × 2	3		

361. Type and Sizes of Motors for Miscellaneous Grinders

Motors 1, 6, or 7

Type of machine	Hp.	Type of machine	Hp.
Wet-tool grinder	2–3	Piston-rod grinder	3
Flexible swinging polish machine	3	Twist-drill grinder	2
Angle-cock grinder	3	Automatic tool grinder	3–5

362. Type and Sizes of Motors for Hammers

Motors 3, 11, or 14

Size, lb.	Hp.	Size, lb.	Hp.
15 75	½ 5	100–200	5–7½

Bliss drop hammers require approximately 1 hp. for every 100-lb. weight of hammer.

363. Type and Sizes of Motors for Slotting and Keyseating Machines

Motors 1, 2, 6, or 7

Stroke, in.	Hp.	Stroke, in.	Hp.
6	3	16	7½
8	3–5	18	7½–10
10	5	20	10 –15
12	5	24	10 –15
14	5–7½	30	10 –15

364. Type and Sizes of Motors for Axle Lathes

Motors 1, 2, 6, 7, or 12

Type of Lathe	Hp.
13-in. center drive or 14-in. end drive	25

365. Type and Sizes of Motors for Engine Lathes

Motors 1, 2, 6, 7, or 12

Swing, in.	Hp.		Swing, in.	Hp.	
	Average	Heavy		Average	Heavy
12	½	2	24–27	10	15
14	2	3	30	15	20
16	3	5	32–36	20	25
18	5	7½	38–42	20	25
20–22	7½	10	48–54	25	30

366. Type and Sizes of Motors for Universal Milling Machines

Motors 1, 2, 6, 7, or 12

Feed, in.		Hp.	Feed, in.		Hp.
Table	Cross		Table	Cross	
22	8	1½–5	34	12	5–7½
28	10	3 –5	42	14	10–15

367. Type and Sizes of Motors for Plain Milling Machines

Motors 1, 2, 6, 7, or 12

Feed, in.		Hp.	Feed, in.		Hp.
Table	Cross		Table	Cross	
22	8	3 – 5	42	14	10–15
28	10	5	50	14	15–20
34	12	7½–10			

368. Type and Sizes of Motors for Vertical Milling Machines

Motors 1, 2, 6, 7, or 12

Height under spindle, in.	Hp.	Height under spindle, in.	Hp.
14	2–3	22	10–15
18	3–5	24	20
20	5–7½		

369. Type and Sizes of Motors for Horizontal-slab Millers

Motors 1, 2, 6, 7, or 12

Width between housings, in.	Hp.	Width between housings, in.	Hp.
14	5	36	35–50
16	7½	42	40–60
18	7½–10	48	40–60
20	10 –15	54	40–60
24	20 –35	72	50–75
30	20 –40	90	50–75

370. Type and Sizes of Motors for Continuous Milling Machines

Motors 1, 2, 6, 7, or 12

Diam. of Table, In.	Hp.
24	7½
30	7½
36	10
48	15

371. Type and Sizes of Motors for Pipe-threading and Cutoff Machines

Motors 1, 2, 6, 7, 11, 12, or 14

Size pipe, in.	Hp.	Size pipe, in.	Hp.
¼–2	3	2½– 8	10
¼–3	3	4 –12	15
1 –4	3–5	8 –18	20
1 –6	7½	10 –20	25

372. Type and Sizes of Motors for Rotary Planers

Motors 1, 2, 6, 7, or 12

Diam. of cutter, in.	Hp.	Diam. of cutter, in.	Hp.
24–26	5	60	15–20
30	7½	72	25
36–42	10	84	30
48–54	15	96–100	40

373. Type and Sizes of Motors for Reciprocating Table Planers
Motors 1, 2, 6, 7, or 12

Width, in.	Type of duty		
	Ordinary, general purpose, hp.	Light, lightly constructed planers, average cuts, hp.	Heavy, heavy planers, heavy cuts, hp.
36	10	10	15
48	15	10	20
56	15	15	20
60	20	15	25
72	25	20	35
84	25	25	35
96	35	25	50
120	35	35	75
144	50	50	75
192	75	50	100

374. Type and Sizes of Motors for Heavy Forge Planers
Motor—Adjustable-speed shunt with compensating windings

Size, ft.	Hp.		Size, ft.	Hp.	
	Platen	Crossrail		Platen	Crossrail
12 × 10	60	10	14 × 22	75	12

375. Type and Sizes of Motors for Punches and Shears
Motors 3, 11, or 14

Punch, size of hole, in.	Shear, size of bar, in.	Hp.	Punch, size of hole, in.	Shear, size of bar, in.	Hp.
3/8 × 1/4	2 3/4 × 1/4	1	1 1/4 × 1	7 × 1	7 1/2 – 10
1/2 × 1/2	3 × 1/2	2–3	1 3/4 × 1	8 × 1 1/8	10–15
5/8 × 5/8	3 × 5/8	2–3	2 1/4 × 1 1/8	9 × 1 1/4	15
3/4 × 3/4	.....	3–5	2 1/4 × 1 3/8	10 × 1 1/4	20
7/8 × 3/4	5 × 3/4	5	2 1/2 × 1 1/2	11 × 1 1/2	20
1 × 1/2	.....	5	3 × 2	10 × 2 1/2	25
1 × 1	6 × 7/8	7 1/2			

376. Type and Sizes of Motors for Lever Shears

Motors 3, 11, or 14

Size, in.	Hp.	Size, in.	Hp.
1 × 1	5	1 × 7	15
1½ × 1½	7½	2¾ × 2¾	20
2 × 2	10	1½ × 8	25
6 × 1	15	3½ × 3½	30
2½ × 2½	15	4½ round	30

377. Type and Sizes of Motors for Plate Shears

Motors 3, 11, or 14

Size of plate, in.	Length of stroke, in.	Hp.	Size of plate, in.	Length of stroke, in.	Hp.
⅜ × 24	3	10	1½ × 42	4½	60
1 × 24	3	15	1¼ × 54	6	75
2 × 14	4¼	30	1½ × 72	5½	100
1 × 42	4	20			

378. Type and Sizes of Motors for Shears

Motors 3, 11, or 14

Width, in.	To cut ⅛-in. iron	To cut ¼-in. iron	Width, in.	To cut ⅛-in. iron	To cut ¼-in. iron
	Hp.			Hp.	
30–42	3	5	72–96	5	10
50–60	4	7½			

379. Type and Sizes of Motors for Nut Tappers

Motors 1, 2, 6, 7, or 12

Type of machine	Size, in.	Hp.	Type of machine	Size, in.	Hp.
4 spindle	1–2	3	10 spindle	2	5
6 spindle	2	3			

380. Type and Sizes of Motors for Cold Cutoff Saws

Motors 1, 2, 6, 7, or 12

Diam. of saw, in.	Hp.	Diam. of saw, in.	Hp.
20	5	48	25
26	10	56	30
32	15	62	35
36	20	72	40
42	25	90	60

381. Type and Sizes of Motors for Shapers

Motors 1, 2, 6, 7, or 12

Stroke, in.	Hp.	Stroke, in.	Hp.
12–16–18	2–5	24–28	5–10
20	3–7½		

382. Type and Sizes of Motors for Crank Slotters

Motors 1, 6, or 7

Size, in.	Hp.	Size, in.	Hp.
6	2 – 3	18	7½–10
8	3	20–24	10 –15
10–12	5 –7½	24–30	10 –20
15	7½–10		

383. Type and Sizes of Motors for Wheel Lathes

Motor 2 or 14		Motor 3 or 11	Motor 2 or 14		Motor 3 or 11
Size, in.	Hp.	Hp. for tailstock	Size, in.	Hp.	Hp. for tailstock
48	15–20	5	90	30–50	10
51–60	15–20	5	100	40–50	10
79–84	25–30	5			

384. Type and Sizes of Motors for Hydrostatic Wheel Presses

Motors 1, 6, or 7

Size, tons	Hp. for pump	Size, tons	Hp. for pump
100	5	400	10
200–300	7½	600	15

385. Operating Speeds of Various Machine Tools

Saws, circular, wood	9,000 ft. per min. at rim
Band, wood	4,000 ft. per min. at rim
Band, hot iron and steel	200–300 ft. per min. at rim
Grindstones	800 ft. per min. at rim
Emery wheels	5,000 ft. per min. at rim
Drills, for wrought iron	12 ft. per min. outer edge
For cast iron	8 ft. per min. outer edge
Milling cutters, for brass	120 ft. per min. outer edge
For cast-rion	60 ft. per min. outer edge
For wrought iron	50 ft. per min. outer edge
Wrought steel	35 ft. per min. outer edge
Screw cutting, gun metal, etc	30 ft. per min. at circum.
Steel	8 ft. per min. at circum.
Boring, cast-iron	10 ft. per min. at circum.
Sawing	
Brass	70 ft. per min. at circum.
Gun metal	30 ft. per min. at circum.
Steel	25 ft. per min. at circum.
Wrought iron	30 ft. per min. at circum.
Cast iron	20 ft. per min. at circum.

386. Motor-driven Pumps (Westinghouse *Diary*).—Either d-c or a-c motors are satisfactory. For most cases, shunt-wound, d-c or squirrel-cage, a-c motors, and synchronous motors in sizes above 25 hp. are suitable; but when the starting conditions are severe, as when the pump must be started against a full discharge pipe, compound-wound, d-c and phase-wound, a-c motors are preferable.

387. Power Required for Printing Machinery

(W. O. Webber, *Power*)

	Hp.
30 × 52 in., 2 rev., No. 8 Cottrell press, 19 impressions per min	1.19
27 × 41 in., No. 20 Adams press, 16 impressions per min	0.68
32 × 54 in., Huber perfecting press	2.44
43 × 64 in., Huber perfecting press, automatic feed	5.55
27 × 41 in., No. 4 Adams job press	0.43
26 × 40 in., No. 2 Adams job press	0.34
32 × 54 in., No. 1 Potter cylinder roller press	0.50
26 in., No. 1 Hoe perfecting press	5.41
Web paper-wetting machine	0.52
Newspaper presses:	
One 10-page web perfecting press, 12,000 per hr	15.39
One 10-page web perfecting press, 24,000 per hr	31.00
One 12-page web perfecting press, 12,000 per hr	20.45
One 12-page web perfecting press, 24,000 per hr	29.56
One 32-page web perfecting press, 12,000 per hr	28.73
Calico-printing machinery, 100 yd. goods per min.:	
One 19-cylinder, soaper and drier, full, 110 r.p.m	3.97
One cutting machine, full, 65 r.p.m	2.77
One set drying cans to cutting machine, full, 110 r.p.m	2.33
One back starcher, 3 wide machines, full 115 r.p.m	4.24
One indigo skying machine, 5 vats all working full, 64 r p.m	4.78
One 40-in., 5-roll calender, working full, 234 r.p.m	9.80
One single-color printing machine	10.60

388. Power Required to Drive Printing Presses
(Walter Scott and Co. specifications[1])

Type of press	Mach. No.	Size of bed, in.	Imp. per hour	Rev. of shaft per imp.	Hp. motor
Class C, newspaper drum cylinder	5	29 × 42	2,000	5	2
	6	33 × 47	1,800	5	2.5
	7	37 × 51	1,600	5	3
Class D, job news drum cylinder	1	17 × 22	2,800	4	1.5
	3	24 × 29	2,400	5.09	2
	4	26 × 34	2,200	5.07	2.5
	5	29 × 42	2,000	5	2.5
	6	32 × 47	1,800	4.96	3
Class E, high-speed drum	2	20 × 25	3,600	6	2
	3	23 × 31	3,200	6.52	2.5
	4	26 × 36	2,850	7.56	3
	5	29 × 42	2,600	8.08	3.5
Two roller, two rev., high speed	4	26 × 36	2,800	6.8	2.5
	5	29 × 42	2,600	7	3
Four roller, two rev., high speed	4	27.5 × 36	2,600	7.4	3
	5	30.5 × 42	2,400	7.8	3.5
	6	35 × 46	2,200	8.06	4
	7	38 × 48	2,100	8.43	4.5
	8	41.5 × 52	2,000	8.81	5
	9	45 × 56	1,900	9.37	5.5
	10	48.5 × 62	1,800	9.75	6
	11	50 × 66	1,700	9.75	6

[1] Walter Scott and Co. recommend 1 hp. more than is called for in each case, as this gives a liberal margin for coolness in running and reserve power for special work.

389. Motor-driven Woodworking Machinery.—Alternating-current, squirrel-cage, constant-speed induction motors form the most suitable drive for the majority of woodworking machines. In some few machines, as in "hogs" for reducing slabs to kindling, high flywheel effect makes starting difficult, and motors with phase-wound rotors and external resistance are preferable. For machines requiring adjustable speed, such as certain types of wood lathes, d-c, shunt-wound motors give the best results because of the greater range of speeds possible.

390. Individual Motor Drive and Group Drive for Woodworking Machinery.—Individual motor drive should be used for single machines that are operated more or less irregularly but at their full capacity. This applies to most woodworking machines. Group drive is satisfactory for machines used frequently but not simultaneously. Thus an emery

wheel, knife grinder, carving machine, cabinet saw, and disk sander can all be run by one motor, which can have a capacity of considerably less than the aggregate rating of the machines it is used to drive.

391. Size of Motor Required to Drive Woodworking Tools

Machine	Size	Motor hp.
Jointers	Small	2
	Large	5–7½
Inside molders	8 × 4	15
	15 × 6	20–30
Outside molders	4 × 4	5
	8 × 4	10
	14 × 5	20
Mortising machines	.....	3–5
Planers, matchers, and molders	9 × 6	30
	30 × 12	40
Surfacers	Small, slow feed	5
	Large, rapid feed	30
Belt sanders	.....	3–5
Column sanders	.....	3
Disk sanders	.....	3
Drum sanders	16-in. drum	3
	42-in. drum	10
	60-in. drum	20
	80-in. drum	30
	102-in. drum	40
Spindle sanders	.....	3
Band saws	Small	3
	Large	20
Band resaws	8 × 24	15
	28 × 36	40
Circular saws, single cutoff	14 in.	3
	36 in.	5
	60 in	60
Circular rip saw	14 in.	10
	36 in.	15
Timber sizers	.....	30–50
Tenonizing machines	Small	3–5
	Large	10–15

392. Foundations are necessary ("Practical Electricity") to support and maintain in alignment generators and other electrical machines of any considerable size. Foundations are made of masonry. Brick or stone set in mortar (preferably cement mortar) will do, but concrete is almost universally used because it is usually the cheaper. A 1:3:6 (1 part cement, 3 parts sand, and 6 parts crushed stone or gravel by bulk) or even a 1:3:7 mixture of concrete will give excellent results. Brick or stone for foundations can be set in mortar consisting of 1 part cement and 3 parts sand.

393. The size of a foundation is determined by the size of the machine supported and by the stresses imposed by the machine. The area of base of any foundation must be great enough so that its weight and the weight of the machine supported will not cause it to sink into the soil. Where a machine is not subjected to any external forces, *i.e.*, where it is self-contained, the only requirement of the foundation (provided the machine is not one that vibrates excessively) is to keep it from sinking into the ground and the lightest possible foundation that will do this will be satisfactory. Therefore motor generators and rotary converters do not require heavy foundations. Machines that are driven by or drive external apparatus require foundations heavy enough to resist the tendency of the external apparatus to tip or to displace the foundation. No rule can be given for determining the proper weight for a foundation, in such a case. However, with a solid foundation, it is usually true that if the foundation is large enough to include all the foundation bolts of the machine and to extend to good bottom, it will be sufficiently heavy. Experience is required to enable one to design the lightest possible foundation that will do, so it is well for the beginner to be sure that his foundation is heavy enough.

394. Alignment of Motors.—After the motor is properly located and the right kind of mounting has been built, the next step is to align the motor properly with its drive. The following procedure is recommended by the General Electric Co.: Belt drive is the most common form of mechanical transmission, but the principles involved and the methods used in aligning apply, in general, equally well for chain drive. The tools usually used for aligning motors or line shafting are the square, plumb bob, and level. Tool manufacturers also build combination squares and levels and similar tools that are a material aid in quickly and accurately aligning machinery.

The first step to be taken when aligning two machines is to see if they are level. It is possible for a machine to be out of line in more than one plane. If, by placing a level or plumb on the machine, it is found to be out a certain amount, the motor must then be mounted so that it will also be out a like amount.

A simple and easy method of aligning a motor pulley with the driven pulley is shown in Fig. 152. First, the crown or center line of the pulleys must be on the same center line, and, second, the motor shaft must be parallel to the driven shaft.

By using a plumb bob and drawing a datum line on the floor, a base of operation is established. Next, drop a plumb line from the center of the driven pulley to the floor. With a square, draw a line perpendicular to the datum line. Next, drop a plumb line from the center of the motor pulley and move the motor up or back until the plumb bob rests on the center line of the driven pulley. From the pulley center line, perpendiculars may be drawn through the centers of the holes in the motor feet.

A level should be used to see that the line shafting is level. If it is not, then the motor feet must be shimmed up so that the motor shaft and the line shaft will be "out of level" the same amount. Chain drive may be aligned in a similar manner.

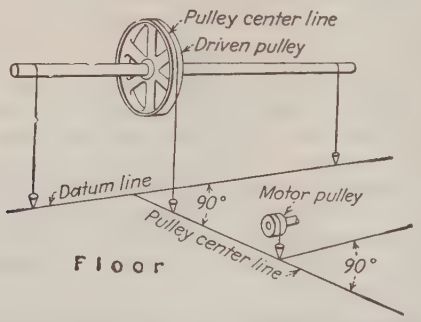


FIG. 152.—Method of aligning two pulleys. (*General Electric Co.*)

With belt drive, a sliding base is nearly always used to allow for belt adjustment. Another method, therefore, is to use the following procedure when aligning two pulleys:

1. Place the motor on the base so that there will be an equal amount of adjustment in either direction and firmly fasten the motor to the base by means of the four holding-down bolts.
2. Mount the motor pulley on the motor shaft.
3. Locate the base and motor in approximately the final position, as determined by the length of belt.
4. Stretch a string from the face of the driven pulley toward the face of the motor pulley.
5. Parallel the face of the motor pulley with this string.
6. Using a scratch pin, mark the end positions of the sliding base.
7. Extend these lines.
8. Move the base and motor away from the string an amount equal to one-half the difference in face width of the two pulleys. Use the two extended lines as a guide to keep the base in its proper position.
9. The belt should now be placed on the pulleys to see if it operates satisfactorily. If it does not operate properly, the base may be shifted slightly until proper operation is obtained.
10. Finally, firmly fasten the base to the floor, ceiling, or side walls by means of lag screws or bolts.

394A. Minimum Pulley Dimensions Recommended by the National Electrical Manufacturer's Association

Horsepower at				Minimum pulley		Belt width, in.
3,600[a] r.p.m.	1,800 r.p.m.	1,200 r.p.m.	900 r.p.m.	Diam. in.	Width over-all, in.	
1–1½	1	¾–1	½	2½	3	2½
2–3	1½	1½	¾	2½	4½	4
....	2	....	1	2½	4½	4
5	3	2	....	3	4½	4
....	....	....	1½	3	4½	4
7½	5	3	2	3½	4½	4
10	7½	5	3	4	5½	5
15	10	7½	5	5	6¾	6
20	....	....	....	5	6¾	6
....	15	10	7½	6	7¾	7
....	20	....	....	7	9¾	9
....	....	15	10	6	9¾	9
....	25	....	....	8	9¾	9
....	....	20	15	6	11	10
....	30	....	....	9	11	10
....	....	25	20	8	11	10
....	40	....	....	9	13	12
....	....	30	25	8	13	12
....	....	40	30	10	13	12
....	....	50	40	10	15	14
....	....	60	....	12	17	16
....	....	....	50	11	17	16

[a] NOTE.—Pulleys for these ratings do not apply for d-c motors. It is recommended that these motors be direct connected.

395. In designing a V-belt drive the following factors should be considered: speed-reduction factor, pitch diameters of pulleys, belt speed, distance between pulley centers, cross-sectional size of belt, and number of belts to use.

395A. The method of designing V-belt drives for satisfactory operation is outlined as follows through the courtesy of the Allis-Chalmers Manufacturing Co.

1. Determine the speed ratio $= \frac{\text{motor r.p.m.}}{\text{machine r.p.m.}}$.

2. From Table 396*A* determine the section of V belt to use, according to the horsepower and synchronous-speed rating of the motor. Where two sections are given, the design should be made for both and then a decision made at the end as to which should be used.

3. From Table 396*C* and the speed ratio determined in 1, select pitch diameters for the sheaves. Pitch diameter for the machine sheave should equal the pitch diameter for the motor sheave multiplied by the speed ratio. The motor sheave should not be too small, as the horsepower transmitted increases with the increase in size of the small sheave.

The machine sheave must not be too large, however. Consideration must be given to the size of the machine and the available space for the sheave.

4. From Table 396*D* determine the service factor for the drive, according to the type of motor and type of machine.

5. From Table 396*E* determine the arc of contact of the V belt on the small sheave and the correction factor for belt horsepower.

6. Compute the horsepower required for the belts by multiplying the rated motor horsepower by the service factor obtained from 4.

7. Compute the velocity of the belt $= \frac{\pi dn}{12}$, where d = diameter of motor sheave in inches; and n = approximate full-load speed of motor.

8. From Table 396*F* determine the horsepower rating of each belt, according to the belt velocity and the pitch diameter of the motor sheave.

9. Determine the number of belts required =

$$\frac{\text{horsepower required (from 6)}}{\text{horsepower rating of belt (from 8)} \times \text{service factor (from 4)}}$$

Use the next larger whole number. This should preferably be a small number, such as 4 or 5, although in the case of large horsepower ratings or low speeds a larger number may be necessary. In case of doubt try the next larger belt section and recalculate.

396A. V Belt Sections to Use

Hp. rating of motor	Syn. speed of motor	V-belt section	Hp. rating of motor	Syn. speed of motor	V-belt section
1½ and less	All	*A*	60	1,800	*C*
			60	1,200–900	*C* or *D*
2–7½	All	*A* or *B*	60	720 and less	*D*
7½	900 and less	*B* or *C*	75	1,800	*C*
			75	1,200–900	*C* or *D*
10	1,800	*A* or *B*	75	720 and less	*D* or *E*
10	1,200–900	*B*			
10	720 and less	*B* or *C*	100	1,800	*C*
			100	1,200 and less	*D*
15	1,800	*B*			
15	1,200–900	*B* or *C*	125	1,200–900	*D*
15	720 and less	*C*	125	720 and less	*D* or *E*
20	1,800	*B* or *C*	150	1,200–900	*D*
20	1,200 and less	*C*	150	720 and less	*E*
25–30	All	*C*	200	1,200–900	*D*
			200	720 and less	*E*
40	1,800	*C*			
40	1,200–900	*C* or *D*	250 and over	All	*E*
40	720 and less	*D*			
50	1,800–900	*C* or *D*			
50	720 and less	*D*			

396B. Standard Sections of V Belts

Section	Greatest width, in.	Thickness, in.	Section	Greatest width, in.	Thickness, in.
A	½	11/32	*D*	1¼	¾
B	21/32	7/16	*E*	1½	1
C	⅞	17/32			

396C. Standard Pitch Diameters for Sheaves for V-belt Drives
(Allis-Chalmers Manufacturing Co.)

Section *A*	Section *B*	Section *C*	Section *D*	Section *E*	Section *A*	Section *B*	Section *C*	Section *D*	Section *E*
Pressed steel		Cast iron			Pressed steel		Cast iron		
3.0	5.4	9.0	13	20	12	15	38	48	72
3.2	5.6	9.2	13.4	21	13	16	40	50	74
3.4	5.8	9.4	13.8	22	14	17	42	52	76
3.6	6.0	9.6	14	23	15	18	44	54	78
3.8	6.2	9.8	14.2	24	16	19	46	56	80
4.0	6.4	10.0	14.6	25	17	20	48	58	82
4.2	6.6	10.2	15	26	18	21	50	60	84
4.4	6.8	10.6	15.4	27	19	22	52	62	86
4.6	7.4	11	16	28	20	23	54	64	88
4.8	8.6	12	17	29	21	24	56	66	90
5.0	9.4	13	18	30	22	25	58	68	92
5.2	11.0	14	19	31	23	26	60	70	94
5.4	12.4	15	20	32	24	27	62	72	96
5.6	15.4	16	21	33	25	28	64	74	
5.8	18.4	17	22	34	26	29	66	76	
6.0	Cast iron	18	23	35	27	30	68	78	
6.2	5.4	19	24	36	28	31	70	80	
6.4	5.6	20	25	38	29	32	72	82	
7.0	5.8	21	26	40	30	33	..	84	
8.2	6.0	22	27	42	31	34	..	86	
9.0	6.2	23	28	44	32	35	..	88	
10.6	6.4	24	29	46	33	36	..	90	
12.0	6.6	25	30	48	34	38	..	92	
15.0	6.8	26	31	50	35	40	..	94	
18.0	7.0	27	32	52	36	42	..	96	
Cast iron	8.0	28	33	54	38	44			
4	8.6	29	34	56	40	46			
5	9.0	30	35	58	..	48			
6	10.0	31	36	60	..	50			
7	11.0	32	38	62	..	52			
8	12.0	33	40	64	..	54			
9	13.0	34	42	66	..	56			
10	13.6	35	44	68	..	58			
11	14	36	46	70	..	60			

396D. Service Factors for Horsepower Loads on V-belt Drives

(Allis-Chalmers Manufacturing Co.)

Applications	Electric motors										Engines			
	A-c.								D-c.		Gas and diesel			
	Squirrel cage				Synchronous		Single phase							
	Normal torque, line start	Normal torque, compensator start	High torque	Wound rotor (slip-ring)	Normal torque	High torque	Repulsion and split-phase	Capacitor	Shunt wound	Compound wound	4 or more cyl.; above 700 r.p.m.	4 or more cyl.; below 700 r.p.m.	Steam	Line shafts and clutch starting
Agitators, paddle-propeller:														
Liquid	1.0	1.0	1.2											
Semiliquid	1.2	1.0	1.4	1.2										
Brick and clay machinery:														
Auger machines	...	1.2	1.4	1.4	...	...	...	...	1.4	...	...	...	...	2.0
De-airing machines	...	1.2	1.4	1.4	...	...	...	...	1.4	...	...	...	...	2.0
Cutting table	...	1.2	1.4	1.4	...	...	...	...	...	...	...	...	...	2.0
Pug mill	1.5	1.3	1.8	1.5										
Mixer	...	1.2	1.6	1.4										
Granulator	...	1.2	1.4	1.4										
Dry press	...	1.2	1.6	1.4										
Rolls	...	1.2	1.4	1.4										
Bakery machinery:														
Dough mixer	1.2	...	...	...	...	...	1.2	1.0						
Compressors:														
Centrifugal	1.2	1.2	...	1.4	1.4	...	...	...	1.2	...	1.2			
Rotary	1.2	1.2	...	1.4	1.4	...	1.2	1.2	1.2	...	1.2			
Reciprocating:														
3 or more cylinders	1.2	1.2	...	1.4	1.4	...	...	...	1.2					
1 or 2 cylinders	1.4	1.4	...	1.5	1.5	...	...	...	1.2					
Conveyors:														
Apron	...	1.4	1.6	...	...	...	...	...	1.4	...	...	...	...	1.6
Belt (ore, coal, sand)	...	1.2	1.4	...	...	...	...	...	1.2	...	...	...	...	1.4
Belt (light package)	...	1.0	1.1	...	...	...	...	...	1.0	...	...	...	...	1.2
Oven	...	1.0	1.1	...	...	...	...	...	1.0	...	...	...	...	1.2
Screw	...	1.6	1.8	...	...	...	...	...	1.6	...	...	...	...	1.8
Bucket	...	1.4	1.6	...	...	...	...	...	1.4	...	...	...	...	1.6
Pan	...	1.4	1.6	...	...	...	...	...	1.4	...	...	...	...	1.6
Flight	...	1.6	1.8	...	...	...	...	...	1.6	...	...	...	...	1.8
Elevator	...	1.4	1.6	...	...	...	...	...	1.4	...	...	...	...	1.6
Crushing machinery:														
Jaw crushers	...	1.4	1.6	1.4	...	...	...	...	...	1.4	1.4	...	...	1.6
Gyratory crushers	...	1.4	1.6	1.4	1.4	1.6	...	...	...	1.4	1.4	...	...	1.6
Cone crushers	...	1.4	1.6	1.4	...	...	...	...	...	1.6	1.4	...	...	1.6
Crushing rolls	...	1.4	1.6	1.4	...	...	...	...	...	1.4	1.4	...	...	1.6
Ball, pebble and Tube mills	...	1.4	1.6	1.4	1.4	1.6	...	...	...	1.4	1.6	...	...	1.6
	...	1.4	1.6	1.4	1.4	...	...	...	...	1.4	...	...	...	1.6
Fan and blowers:														
Centrifugal	1.2	1.2	...	1.4	..	...	...	...	1.2	...	1.2			
Propeller	1.4	1.4	2.0	1.6	...	2.0	...	...	1.4	...	1.4			
Induced draft	1.2	1.2	...	1.4	...	...	...	...	1.4	...	1.4			
Mine fans	1.6	1.4	2.0	...	...	2.0	...	...	...	...	1.6			
Positive blowers	1.6	1.6	...	2.0	2.0	2.0	...	...	...	...	1.6			
Exhausters	1.2	1.2	...	1.4	...	...	...	...	1.4	...	...	...	1.5	1.5
Flour-, feed-, cereal-mill machinery:														
Bolters and sifters	...	1.0												
Grinders and hammer mills	...	1.4	...	...	...	...	...	...	...	...	1.6			

Service Factors for Horsepower Loads on V-belt Drives (*Continued*)

Applications	Electric motors										Engines			
	A-c.								D-c.		Gas and diesel			
	Squirrel cage				Synchronous		Single phase							
	Normal torque, line start	Normal torque, compensator start	High torque	Wound rotor (slip-ring)	Normal torque	High torque	Repulsion and split-phase	Capacitor	Shunt wound	Compound wound	4 or more cyl.; above 700 r.p.m.	4 or more cyl.; below 700 r.p.m.	Steam	Line shafts and clutch starting
Flour-, feed-, cereal-mill machinery:—(*Continued*)														
Purifiers and reels	1.2	1.4												
Main-line shaft drive	1.4	1.4	1.6	1.4	1.4	...	...	...	...	...	1.8			
Separator	1.0	1.0												
Roller mills	...	1.4												
Generator and exciters	1.2	...	...	...	...	...	...	...	1.2	...	2.0	...	1.4	1.4
Laundry machinery:														
Washers	1.2	...	...	...	...	...	...	...	...	1.2				
Extractors	1.2	...	...	...	...	...	...	...	...	1.2				
Tumblers	1.2	...	...	...	...	...	...	...	...	1.2				
Dampeners	1.2	...	...	...	...	...	...	...	...	1.2				
Flatwork ironers	1.2	...	...	...	...	...	...	...	...	1.2				
Line shafts	1.4	1.4	...	1.4	1.4	2.0	1.4	1.4	1.4	1.4	1.6	...	1.6	1.6
Machine tools:														
Grinders	1.2	...	...	1.4	...	...	1.2	1.0	1.2	1.2				
Boring mills	1.2	...	...	1.4	...	...	...	...	1.2	1.2				
Lathes	1.0	...	...	1.2	...	...	1.0	1.0	1.0	1.0				
Milling machines	1.2	...	...	1.4	...	...	...	...	1.2	1.2				
Screw machines	1.0	...	...	1.0	...	...	1.0	1.0	1.0	1.0				
Cam cutters	1.0	...	...	1.0	...	...	...	...	1.0	1.0				
Planers	1.2	...	...	1.4	...	...	1.2	1.0	1.2	1.2				
Shapers	1.0	...	...	1.0	...	...	1.0	1.0	1.0	1.0				
Drill press	1.0	...	...	1.0	...	...	1.0	1.0	1.0	1.0				
Drop hammers	1.0	...	...	1.0	...	...	1.0	1.0	1.0	1.0				
Shears	1.2	...	...	1.4	...	...	1.2	1.2	1.2	1.0				
Mills:														
Pebble	...	1.4	1.6	1.4	...	...	...	...	...	1.4	...	...	...	1.6
Rod	...	1.4	1.6	1.4	...	...	...	...	...	1.4	...	...	...	1.6
Ball	...	1.4	1.6	1.4	...	...	...	...	...	1.4	...	...	...	1.6
Roller mills	...	1.4	1.6	1.4	...	...	...	...	...	1.4	...	...	...	1.6
Flaking mills	...	1.6	1.6	1.4	...	...	...	...	...	1.4	...	...	...	1.6
Tumbling barrels	...	1.6	1.6	1.4	...	...	...	...	...	1.4	...	...	...	1.6
Oil-field machinery:[a]														
Slush pumps	...	...	...	...	...	...	...	...	1.4	...	1.4	1.6	1.4	1.4
Pumping units	1.2	1.2	1.4	...	...	...	...	...	1.4	...	...	...	...	1.6
Pipe-line pumps, centrifugal	1.2	1.2	1.4	...	...	...	...	...	1.4	1.4				
Draw works (intermittent)	...	...	...	...	...	...	...	...	1.3	...	1.0	1.0		
Paper machinery:														
Jordan engines	1.5	1.3	1.8	1.5	1.6	1.8	...	...	1.5	1.5				
Beaters	1.4	1.4	...	1.4	...	...	...	...	1.4	1.4	...	...	...	1.8
Calenders	1.2	1.2	...	1.2	...	...	...	...	1.2	1.2				
Agitators	1.2	1.0	1.4	1.2	...	...	...	...	1.2	1.2	...	...	...	1.6
Driers	1.2	1.2	...	1.2	...	...	...	...	1.2	1.2				
Paper machines	1.4	1.4	...	1.5	...	...	...	...	1.5	1.5	...	...	...	1.6
Printing machinery:														
Rotary press	1.2	1.2	...	1.2	...	...	...	...	1.2					

[a] Hoisting service factor based on total engine horsepower (continuous rating). Electric drive factor based on continuous rating of motor.

Service Factors for Horsepower Loads on V-belt Drives (*Continued*)

Applications	Electric motors										Engines			
	A-c.								D-c.		Gas and diesel			
	Squirrel cage				Synchronous		Single phase							
	Normal torque, line start	Normal torque, compensator start	High torque	Wound rotor (slip-ring)	Normal torque	High torque	Repulsion and split-phase	Capacitor	Shunt wound	Compound wound	4 or more cyl.; above 700 r.p.m.	4 or more cyl.; below 700 r.p.m.	Steam	Line shafts and clutch starting
Printing machinery:—(*Continued*)														
Embossing press	1.2	1.2	...	1.2	...	...	...	...	1.2	1.2				
Folders	1.2	1.2	...	1.2	...	...	...	...	1.2					
Paper cutters	1.2	1.2	...	1.2	...	...	...	...	1.2	1.2				
Linotype machines	1.2	1.2	...	...	...	...	...	...	1.2					
Flat-bed press	1.2	1.2	...	1.2	...	...	...	...	1.2					
Pumps:														
Centrifugal	1.2	1.2	1.4	1.4	...	...	1.2	1.2						
Gear	1.2	1.2	1.4	1.4	...	...	1.2	1.2						
Rotary	1.2	1.2	1.4	1.4	...	...	1.2	1.2	1.2	...	1.2			
Reciprocating:														
3 or more cylinders	1.2	1.2	...	1.4	1.4	1.6	...	...	...	...	1.8	...	1.8	
1 or 2 cylinders	1.4	1.4	...	1.6	1.6	1.8	...	...	...	...	2.0	...	2.0	
Dredge pumps	1.4	1.4	...	1.4	...	...	...	...	...	...	2.0	...	2.0	
Rubber-plant machinery:														
Calenders	1.4	1.4	1.4	1.4	...	1.8	...	...	...	...	...	...	2.0	
Banbury mills	1.4	1.4	1.4	1.4	...	1.8	...	...	...	...	...	...	2.0	
Mixers	1.4	1.4	1.4	1.4	...	1.8	...	...	...	...	...	...	2.0	
Screens:														
Vibrating	1.2	1.2	1.4											
Conical	1.2	1.2												
Revolving	1.2	1.2												
Textile machinery:														
Spinning frames	1.6	...	1.8											
Twisters	1.6	...	1.8											
Looms	1.2													
Warpers	1.2													
Reels	1.2													

396E. Correction Factors for Horsepower Rating of V Belts According to Arc of Contact on Small Sheave

Arc of contact,[a] deg.	V-belt sheaves on both shafts	V-belt sheave to flat pulley	Arc of contact,[a] deg.	V-belt sheaves on both shafts	V-belt sheave to flat pulley
	Correction factor			Correction factor	
180	1.00	0.74	130	0.86	0.86
170	0.98	0.77	120	0.83	0.83
160	0.95	0.79	110	0.79	0.79
150	0.92	0.82	100	0.74	0.74
140	0.89	0.84	90	0.69	0.69

[a] Arc of contact $= 180 - \frac{(D - d)60}{C}$

where D = pitch diameter of large pulley (for flat pulleys add the thickness of belt to the pulley diameter); d = pitch diameter of small pulley: and C = center distance.

396F. Horsepower Ratings for V Belts

"A" Section

Velocity, ft. per min.	Pitch diam., in.						
	2.6	3.0	3.4	3.8	4.2	4.6	5.0 and larger
1,000	0.5	0.7	0.8	0.9	0.9	1.0	1.0
1,100	0.6	0.7	0.9	1.0	1.0	1.1	1.1
1,200	0.6	0.8	1.0	1.0	1.1	1.2	1.2
1,300	0.7	0.9	1.0	1.1	1.2	1.3	1.3
1,400	0.7	0.9	1.1	1.2	1.3	1.4	1.4
1,500	0.8	1.0	1.1	1.3	1.4	1.4	1.5
1,600	0.8	1.0	1.2	1.3	1.4	1.5	1.6
1,700	0.9	1.1	1.3	1.4	1.5	1.6	1.7
1,800	0.9	1.2	1.4	1.5	1.6	1.7	1.8
1,900	0.9	1.2	1.4	1.6	1.7	1.8	1.9
2,000	1.0	1.3	1.5	1.6	1.8	1.9	2.0
2,100	1.0	1.3	1.5	1.7	1.9	2.0	2.1
2,200	1.1	1.4	1.6	1.8	1.9	2.0	2.2
2,300	1.1	1.4	1.6	1.8	2.0	2.1	2.3
2,400	1.1	1.4	1.7	1.9	2.0	2.2	2.3
2,500	1.1	1.5	1.7	2.0	2.1	2.3	2.4
2,600	...	1.6	1.8	2.0	2.2	2.3	2.5
2,700	...	1.6	1.8	2.1	2.3	2.4	2.6
2,800	...	1.6	1.9	2.1	2.3	2.5	2.6
2,900	...	1.6	1.9	2.2	2.4	2.6	2.7
3,000	...	...	2.0	2.2	2.4	2.6	2.7
3,100	...	...	2.0	2.3	2.5	2.6	2.8
3,200	...	...	2.0	2.3	2.5	2.7	2.9
3,300	...	...	2.1	2.4	2.6	2.7	2.9
3,400	...	...	...	2.4	2.7	2.8	3.0
3,500	...	...	...	2.5	2.7	2.8	3.0
3,600	...	...	...	2.5	2.7	2.9	3.1
3,700	...	...	...	2.5	2.8	2.9	3.1
3,800	...	...	...	...	2.8	3.0	3.2
3,900	...	...	...	...	2.8	3.0	3.2
4,000	...	...	...	...	2.8	3.0	3.3
4,100	...	...	...	...	2.9	3.1	3.3
4,200	...	...	...	...	...	3.1	3.3
4,300	...	...	...	...	...	3.1	3.3
4,400	...	...	...	...	...	3.2	3.4
4,500	...	...	...	...	...	3.2	3.4
4,600	...	...	...	...	...	...	3.4
4,700	...	...	...	...	...	...	3.4
4,800	...	...	...	...	...	...	3.4
4,900	...	...	...	...	...	...	3.4
5,000	...	...	...	...	...	...	3.4

Horsepower Ratings for V Belts (*Continued*)
"B" Section

Velocity, ft. per min.	Pitch diam., in.					
	5.0	5.4	5.8	6.2	6.6	7.0 and larger
1,000	1.3	1.4	1.5	1.6	1.7	1.8
1,100	1.4	1.5	1.6	1.7	1.8	1.9
1,200	1.5	1.6	1.7	1.8	1.9	2.0
1,300	1.6	1.8	1.9	2.0	2.1	2.2
1,400	1.7	1.9	2.0	2.1	2.2	2.3
1,500	1.8	2.0	2.1	2.3	2.4	2.5
1,600	1.9	2.1	2.3	2.4	2.5	2.6
1,700	2.0	2.2	2.4	2.5	2.7	2.8
1,800	2.2	2.4	2.5	2.7	2.8	2.9
1,900	2.3	2.5	2.6	2.8	3.0	3.1
2,000	2.4	2.6	2.8	2.9	3.1	3.2
2,100	2.4	2.7	2.9	3.1	3.2	3.4
2,200	2.5	2.8	3.0	3.2	3.4	3.5
2,300	2.6	2.9	3.1	3.3	3.5	3.6
2,400	2.7	3.0	3.2	3.4	3.6	3.7
2,500	2.8	3.1	3.3	3.5	3.7	3.9
2,600	2.9	3.2	3.4	3.6	3.8	4.0
2,700	3.0	3.3	3.5	3.7	3.9	4.1
2,800	3.0	3.3	3.6	3.8	4.1	4.3
2,900	3.1	3.4	3.7	3.9	4.2	4.4
3,000	3.2	3.5	3.8	4.0	4.3	4.5
3,100	3.2	3.6	3.9	4.1	4.4	4.6
3,200	3.3	3.6	4.0	4.2	4.5	4.7
3,300	3.3	3.7	4.0	4.3	4.6	4.8
3,400	3.4	3.7	4.1	4.4	4.7	4.9
3,500	3.4	3.8	4.1	4.4	4.7	4.9
3,600	3.4	3.8	4.2	4.5	4.8	5.0
3,700	3.5	3.9	4.3	4.5	4.8	5.1
3,800	3.5	3.9	4.3	4.6	4.9	5.2
3,900	3.5	3.9	4.3	4.6	4.9	5.2
4,000	3.5	4.0	4.4	4.7	5.0	5.3
4,100	3.5	4.0	4.4	4.7	5.0	5.3
4,200	3.5	4.0	4.4	4.7	5.1	5.4
4,300	3.5	4.0	4.4	4.7	5.1	5.4
4,400	3.5	4.0	4.4	4.8	5.1	5.4
4,500	3.5	4.0	4.4	4.8	5.1	5.4
4,600	3.4	4.0	4.4	4.8	5.1	5.5
4,700	3.4	3.9	4.4	4.8	5.2	5.5
4,800	3.4	3.9	4.4	4.8	5.2	5.5
4,900	3.3	3.9	4.3	4.8	5.1	5.5
5,000	3.3	3.8	4.3	4.7	5.1	5.5

Horsepower Ratings for V Belts (*Continued*)

"C" Section

Velocity, ft. per min.	Pitch diam., in.					
	7.0	8.0	9.0	10.0	11.0	12.0 and larger
1,000	2.0	2.5	2.8	3.1	3.4	3.6
1,100	2.2	2.7	3.1	3.5	3.7	3.9
1,200	2.4	2.9	3.4	3.8	4.0	4.3
1,300	2.6	3.2	3.7	4.1	4.4	4.6
1,400	2.7	3.4	3.9	4.4	4.7	5.0
1,500	2.9	3.6	4.2	4.6	5.0	5.3
1,600	3.1	3.9	4.5	4.9	5.3	5.7
1,700	3.3	4.1	4.7	5.3	5.6	6.0
1,800	3.4	4.3	5.0	5.4	5.9	6.3
1,900	3.6	4.5	5.2	5.8	6.2	6.6
2,000	3.7	4.7	5.5	6.1	6.5	7.0
2,100	3.9	4.9	5.7	6.3	6.8	7.3
2,200	4.0	5.1	5.9	6.6	7.1	7.6
2,300	4.2	5.3	6.2	6.8	7.4	7.9
2,400	4.3	5.5	6.4	7.1	7.7	8.2
2,500	4.5	5.7	6.6	7.3	8.0	8.5
2,600	4.6	5.8	6.8	7.6	8.2	8.8
2,700	4.7	6.0	7.0	7.8	8.4	9.0
2,800	4.8	6.2	7.2	8.0	8.7	9.3
2,900	4.9	6.3	7.4	8.3	9.0	9.6
3,000	5.0	6.5	7.6	8.5	9.2	9.8
3,100	5.1	6.6	7.8	8.7	9.5	10.1
3,200	5.2	6.7	7.9	8.9	9.7	10.3
3,300	5.3	6.9	8.1	9.1	9.9	10.6
3,400	...	7.0	8.3	9.3	10.1	10.8
3,500	...	7.1	8.4	9.4	10.3	11.0
3,600	...	7.2	8.5	9.6	10.5	11.2
3,700	...	7.3	8.7	9.8	10.7	11.4
3,800	...	7.4	8.8	9.9	10.9	11.6
3,900	...	...	8.9	10.1	11.0	11.8
4,000	...	...	9.0	10.2	11.2	12.0
4,100	...	...	9.1	10.3	11.3	12.2
4,200	...	...	9.2	10.4	11.5	12.3
4,300	...	...	9.3	10.5	11.6	12.5
4,400	...	...	...	10.6	11.7	12.6
4,500	...	...	...	10.7	11.8	12.7
4,600	...	...	...	10.8	11.9	12.9
4,700	...	...	...	10.8	12.0	13.0
4,800	...	...	...	10.9	12.1	13.3
4,900	...	...	...	....	12.1	13.2
5,000	...	...	...	....	12.2	13.2

Horsepower Ratings for V Belts (*Continued*)
"D" Section

Velocity, ft. per min.	Pitch diam., in.					
	12.0	13.0	14.0	15.0	16.0	17.0 and larger
1,000	4.5	5.1	5.6	6.1	6.5	6.8
1,100	4.9	5.8	6.2	6.7	7.2	7.5
1,200	5.3	6.1	6.7	7.3	7.7	8.2
1,300	5.7	6.5	7.2	7.8	8.4	8.8
1,400	6.1	7.0	7.8	8.4	9.0	9.4
1,500	6.5	7.5	8.2	9.0	9.6	10.1
1,600	6.9	7.9	8.8	9.5	10.2	10.7
1,700	7.3	8.4	9.3	10.1	10.8	11.4
1,800	7.7	8.8	9.8	10.6	11.3	12.0
1,900	8.0	9.2	10.2	11.1	11.9	12.6
2,000	8.4	9.7	10.7	11.7	12.5	13.2
2,100	8.8	10.1	11.2	12.2	13.0	13.8
2,200	9.1	10.5	11.7	12.7	13.6	14.4
2,300	9.5	10.9	12.1	13.2	14.1	14.9
2,400	9.8	11.3	12.6	13.7	14.6	15.5
2,500	10.1	11.6	12.9	14.1	15.1	16.0
2,600	10.4	12.0	13.4	14.6	15.6	16.6
2,700	10.6	12.3	13.8	15.0	16.1	17.1
2,800	10.9	12.7	14.1	15.5	16.6	17.6
2,900	11.2	13.0	14.5	15.9	17.0	18.1
3,000	11.4	13.3	14.9	16.3	17.5	18.6
3,100	11.7	13.6	15.2	16.7	17.9	19.0
3,200	11.9	13.9	15.6	17.1	18.4	19.5
3,300	12.1	14.1	15.9	17.4	18.9	19.9
3,400	12.2	14.4	16.2	17.7	19.1	20.3
3,500	12.4	14.6	16.5	18.1	19.5	20.7
3,600	12.6	14.8	16.7	18.4	19.8	21.1
3,700	12.7	15.0	17.0	18.7	20.2	21.5
3,800	12.8	15.2	17.2	18.9	20.4	22.2
3,900	....	15.3	17.4	19.2	20.7	22.3
4,000	....	15.5	17.6	19.4	21.0	22.5
4,100	....	15.6	17.8	19.6	21.3	22.8
4,200	....	....	17.9	19.8	21.5	23.0
4,300	....	....	18.0	20.0	21.8	23.0
4,400	....	....	18.1	20.1	21.9	23.3
4,500	....	....	....	20.3	22.1	23.5
4,600	....	....	....	20.4	22.3	23.9
4,700	....	....	....	20.5	22.4	24.1
4,800	....	....	....	....	22.5	24.2
4,900	....	....	....	....	22.6	24.3
5,000	....	....	....	....	22.6	24.4

Horsepower Ratings for V Belts (*Continued*)

"E" Section

Velocity, ft. per min.	Pitch diam., in.								
	20	21	22	23	24	25	26	27	28 and larger
1,000	8.0	8.5	9.0	9.4	9.8	10.2	10.5	10.9	11.1
1,100	8.7	9.3	9.8	10.3	10.8	11.2	11.6	11.9	12.2
1,200	9.5	10.1	10.7	11.2	11.7	12.2	12.6	13.0	13.3
1,300	10.2	10.9	11.6	12.1	12.7	13.1	13.6	14.0	14.4
1,400	11.0	11.7	12.4	13.0	13.6	14.1	14.6	15.0	15.4
1,500	11.7	12.5	13.2	13.9	14.5	15.1	15.6	16.1	16.5
1,600	12.4	13.3	14.1	14.8	15.4	16.0	16.6	17.1	17.5
1,700	13.1	14.0	14.9	15.6	16.3	16.9	17.5	18.1	18.6
1,800	13.8	14.8	15.7	16.5	17.2	17.9	18.5	19.0	19.6
1,900	14.5	15.5	16.4	17.3	18.0	18.8	19.4	20.0	20.6
2,000	15.2	16.2	17.2	18.1	18.9	19.6	20.3	21.0	21.6
2,100	15.8	17.0	18.0	18.9	19.7	20.5	21.2	21.9	22.5
2,200	16.5	17.6	18.7	19.7	20.6	21.4	22.1	22.8	23.5
2,300	17.1	18.3	19.4	20.4	21.4	22.2	23.0	23.7	24.4
2,400	17.7	18.9	20.1	21.2	22.2	23.1	23.9	24.6	25.3
2,500	18.3	19.6	20.8	21.9	23.0	23.9	24.7	25.5	26.3
2,600	18.9	20.2	21.5	22.6	23.7	24.7	25.5	26.4	27.1
2,700	19.4	20.8	22.1	23.3	24.4	25.4	26.4	27.2	28.0
2,800	19.9	21.4	22.8	24.0	25.1	26.2	27.1	28.0	28.9
2,900	20.4	22.0	23.4	24.7	25.8	26.9	27.9	28.8	29.7
3,000	20.9	22.7	24.0	25.3	26.5	27.6	28.6	29.6	30.5
3,100	21.4	23.0	24.5	26.0	27.2	28.3	29.4	30.4	31.3
3,200	21.8	23.5	25.1	26.5	27.8	29.0	30.1	31.1	32.0
3,300	22.3	24.0	25.6	27.1	28.4	29.6	30.7	31.8	32.8
3,400	22.6	24.5	26.1	27.6	29.0	30.2	31.4	32.5	33.5
3,500	23.0	24.9	26.6	28.1	29.5	30.8	32.0	33.1	34.2
3,600	23.4	25.3	27.0	28.6	30.0	31.4	32.6	33.8	34.8
3,700	23.7	25.6	27.4	29.1	30.6	31.9	33.2	34.4	35.5
3,800	24.0	26.0	27.8	29.5	31.0	32.4	33.7	34.9	36.1
3,900	24.2	26.3	28.2	29.9	31.5	32.9	34.3	35.5	36.6
4,000	24.5	26.6	28.5	30.3	31.9	33.4	34.7	36.0	37.2
4,100	....	26.8	28.8	30.6	32.3	33.8	35.2	36.5	37.7
4,200	....	27.1	29.1	30.9	32.6	34.2	35.6	37.0	38.2
4,300	....	....	29.3	31.2	33.0	34.6	36.0	37.4	38.7
4,400	....	....	29.5	31.5	33.3	34.9	36.4	37.8	39.1
4,500	....	....	....	31.7	33.5	35.2	36.7	38.2	39.5
4,600	....	....	....	31.9	33.7	35.5	37.0	38.5	39.9
4,700	....	....	....	....	33.9	35.7	37.3	38.8	40.2
4,800	....	....	....	....	34.1	35.9	37.5	39.1	40.5
4,900	....	....	....	....	....	36.0	37.7	39.3	40.7
5,000	....	....	....	....	....	36.2	37.9	39.5	40.9

397. Procedure in Planning a Flat-belt Drive (General Electric Co.).—

1. Check reduction ratio of speed required against limits of Sec. **313.**

2. Determine pulley diameters from Secs. **394A** and **401.**

3. Check available distances between centers of shafts against limits of Secs. **399** and **402.**

4. Determine belt speed from Secs. **400** and **403.**

5. Determine horsepower that will be transmitted per inch of width of belt from Secs. **404** and **405.**

6. Determine width of belt required from Sec. **406.**

7. Determine required width of pulleys from Sec. **407** and check against standard motor-pulley widths from Sec. **394A.**

398. Belt Slip.—The effect of creepage and slip is to reduce the speed of the driven pulley and, consequently, the power transmitted. For commercial applications it will be close enough to multiply the calculated speed of the driven shaft by 98 per cent, assuming 2 per cent slip. The diameter of the driven pulley should be slightly smaller than that calculated on the basis of no slip in order to get a certain speed at the driven shaft. In other words, the speed of the driven shaft is reduced by slip unless compensated for by reducing the driven-pulley diameter a proportionate amount.

A small amount of belt slip is not harmful, but excessive slip is. Severe slippage burns the belt, quickly destroying its usefulness, while, at best, the belt surface is polished so that the grip on the pulley is materially reduced. Belt slip can be detected by noting the condition of the pulley surface. When the belt is slipping, the pulley will have a very shiny appearance, as contrasted with the smooth but rather dull appearance it should have.

Excessive slip is caused by poorly designed drives, where the driving pulley is too small or the load too great; by running the belt too loose; or by not giving proper attention to the care of the belt.

399. Arc of Contact for Flat-belt Drives.—One of the factors affecting the amount of power that can be transmitted by a belt of given width is the arc of contact (the distance the belt wraps around the pulley). As this arc of contact decreases, the belt width must be increased to transmit the same horsepower with 2 per cent slip; Table 405, however, allows a factor of safety sufficient to take care of installations which are in accordance with the recommendations for belt ratios and center distances given in this subdivision. If it is necessary to exceed the limits given, it may be necessary to use a belt tightener.

400. Belt Speeds for Flat Belts

Full-load speed of motor, r.p.m.	Pulley diam., in.										
	3½	4	4½	5	5½	6	7	8	9	10	11
	Belt speed, ft. per min.										
1,750	1,605	1,835	2,060	2,290	2,520	2,750	3,205	3,670	4,125	4,580	5,040
1,450	1,330	1,520	1,710	1,900	2,090	2,275	2,660	3,040	3,420	3,800	4,170
1,150	1,055	1,205	1,355	1,505	1,655	1,810	2,110	2,410	2,710	3,010	3,315
860	790	900	1,015	1,130	1,240	1,350	1,575	1,800	2,030	2,255	2,480
690	.....	725	815	905	995	1,085	1,265	1,445	1,625	1,810	1,990
575	.....	.....	680	755	830	905	1,055	1,205	1,355	1,505	1,655

Full-load speed of motor, r.p.m.	Pulley diam., in.										
	12	13	14	15	16	17	18	19	20	21	22
	Belt speed, ft. per min.										
1,450	4,560	4,930									
1,150	3,615	3,915	4,220	4,520	4,820	5,120					
860	2,705	2,930	3,160	3,380	3,610	3,835	4,060	4,280	4,510	4,740	4,960
690	2,170	2,350	2,530	2,710	2,890	3,075	3,250	3,435	3,615	3,800	3,980
575	1,805	1,955	2,105	2,260	2,410	2,560	2,710	2,860	3,010	3,160	3,310

Full-load speed of motor, r.p.m.	Pulley diam., in.										
	23	24	25	26	27	28	29	30	31	32	33
	Belt speed, ft. per min.										
690	4,160	4,340	4,520	4,700	4,880	5,060					
575	3,460	3,610	3,760	3,915	4,060	4,210	4,360	4,515	4,665	4,815	4,965

The above table is based on the formula

Belt speed in feet per minute =

$$\frac{3.1416 \times \text{pulley diameter in inches} \times \text{r.p.m.}}{12}$$

401. Determining Pulley Diameters.—The following rules are given for determining pulley diameters and speeds:

1. Diameter of driven pulley =
$$\frac{\text{diameter of motor pulley} \times \text{full-load motor speed in r.p.m.}}{\text{r.p.m. of driven pulley}}$$
2. Diameter of motor pulley =
$$\frac{\text{diameter of driven pulley} \times \text{r.p.m. of driven pulley}}{\text{full-load motor speed in r.p.m.}}$$
3. R.p.m. of driven pulley =
$$\frac{\text{diameter of motor pulley} \times \text{full-load motor speed}}{\text{diameter of driven pulley}}$$
4. R.p.m. of motor =
$$\frac{\text{diameter of driven pulley} \times \text{speed of driven pulley}}{\text{diameter of motor pulley}}$$

The above formulas may be applied to any belt drive by substituting the terms "driver" and "r.p.m. of driver" for "motor pulley" and "motor speed."

CAUTION.—The desired driven speed should be increased 2 per cent in above formulas to allow for belt slip.

It is desirable to utilize the standard pulleys furnished with the motors wherever possible. The use of special pulleys on electric motors is limited by mechanical dimensions and by the permissible bearing pressure, which, for the transmission of a certain horsepower, increases as the pulley diameter decreases. The maximum pulley diameter is determined by mechanical dimensions. These are in addition to the usual requirements of proper belt speed and width to transmit the power involved.

402. Center Distances for Flat-belt Drives.—A short center distance is bad for two reasons: it means a shorter belt, so that flexure occurs at each cross section more frequently; and the arc of contact on the smaller pulley frequently becomes so small that power can no longer be effectively transmitted. Two and a half times the diameter of the larger pulley should be the minimum center distance, with from three to five a better figure.

403. Flat-belt Speed.—Belts should not be run at speeds above 5,000 ft. per min. Above this speed there is not sufficient friction contact between belt and pulley, because of the effect of centrifugal force tending to "throw" the belt.

Table 400 gives the belt speed in feet per minute corresponding to various motor speeds and pulley diameters.

404. Horsepower Transmitted by Flat Belts.—The pulley must be large enough to transmit the horsepower, which ordinarily will not be the motor-horsepower rating but a figure somewhat larger, to take care of possible overloads and peak loads. In ordinary applications, 125 per cent of the motor rating may be allowed for a safety factor in the usual sizes of motors.

In general, the product of the diameter and belt width of a *special* pulley should at least equal the product of the corresponding dimensions of the *standard* pulley recommended for that size and speed of motor. Assuming that the diameters have been tentatively chosen as best for the desired purpose, the horsepower that can be transmitted will depend upon the pulley material, the belt width, its quality and number of plies, the distance between centers, and the relative angular location of the driving and driven pulley.

Table 405 shows the horsepower per inches of width transmitted by good leather belting running over paper pulleys with 180-deg. arc of contact and no slip. For iron pulleys, multiply figures given by 0.62; for wood pulleys, multiply by 0.41 (for belt speeds, see Table 400).

405. Horsepower Transmitted per Inch of Width of Flat Leather Belts

To obtain the horsepower transmitted by belts of any width, multiply the figure shown for the given belt speed by the width of the belt used.

Belt speed, ft. per min.	Hp. per in. of width	Belt speed, ft. per min.	Hp. per in. of width	Belt speed, ft. per min.	Hp. per in. of width	Belt speed, ft. per min.	Hp. per in. of width
Single Belting							
900	1.25	2,000	2.78	3,100	4.31	4,200	5.84
1,000	1.39	2,100	2.92	3,200	4.45	4,300	5.98
1,100	1.53	2,200	3.06	3,300	4.59	4,400	6.12
1,200	1.67	2,300	3.20	3,400	4.72	4,500	6.26
1,300	1.81	2,400	3.33	3,500	4.86	4,600	6.40
1,400	1.95	2,500	3.47	3,600	5.00	4,700	6.54
1,500	2.09	2,600	3.61	3,700	5.14	4,800	6.68
1,600	2.22	2,700	3.75	3,800	5.28	4,900	6.82
1,700	2.36	2,800	3.89	3,900	5.42	5,000	6.96
1,800	2.50	2,900	4.03	4,000	5.56		
1,900	2.64	3,000	4.17	4,100	5.70		
Double Belting							
900	1.79	2,000	3.97	3,100	6.16	4,200	8.34
1,000	1.99	2,100	4.17	3,200	6.36	4,300	8.54
1,100	2.19	2,200	4.37	3,300	6.55	4,400	8.74
1,200	2.39	2,300	4.57	3,400	6.75	4,500	8.94
1,300	2.58	2,400	4.77	3,500	6.95	4,600	9.13
1,400	2.78	2,500	4.97	3,600	7.15	4,700	9.33
1,500	2.98	2,600	5.16	3,700	7.35	4,800	9.53
1,600	3.18	2,700	5.36	3,800	7.55	4,900	9.73
1,700	3.38	2,800	5.56	3,900	7.74	5,000	9.93
1,800	3.58	2,900	5.76	4,000	7.94		
1,900	3.78	3,000	5.96	4,100	8.14		

The figures shown in Table 405 are for "regular" single-ply and double-ply belts. The values for horsepower transmitted by "light" belts will be 80 per cent of values shown, and by "heavy" belts, 115 per cent of values shown.

406. Belt Width for Flat Belts.—For a given diameter, the minimum belt width is determined by the horsepower to be transmitted; the maximum width is limited by the possible overhang and the safe strain which may be placed on the bearing.

To obtain the belt width necessary to transmit a given horsepower, divide the horsepower which is to be transmitted by the figures given in Table 405, if paper pulleys are used. For iron pulleys, multiply the quotient thus obtained by 1.6; for wood pulleys, by 2.4.

Stock sizes of belts increase in width by the following increments:

Belt Width, In.	Increment, In.
½–1	⅛
1 –4	¼
4 –7	½
7 –30	1
30 –56	2
Above 56	4

The foregoing represents average practice; stock sizes of different manufacturers may vary slightly from the figures given.

NOTES.—A good handy rule to remember is: A single-ply belt 1 in. wide and running at 1,000 ft. per min. will deliver approximately 1 hp. (up to about 3,000 r.p.m.).

Round belts of 0.25 and 0.5 in. diameter are fully equal to single belts of 1 and 3 in., respectively.

407. Pulley widths should exceed belt widths by following amounts:

Pulley diam., in.	Iron pulley, in.	Paper pulley, in.
Under 2	¼	¼
2– 5	¼	½
5–10	½	¾
10–20	½	1
20–24	¾	1
24–36	¾	1½
Above 36	¾	2

408. Arrangement of Belts and Pulleys.—A typical belt-drive layout is shown in Fig. 153. The best arrangement of belts and pulleys is with the center line through the pulleys in a horizontal plane. This is called horizontal drive. The drive should be arranged so that the lower side of the belt is driving in order that the sag of the upper side of the belt will tend to increase the arc of contact. This is illustrated in Fig. 154.

The sag should be about 1½ in. for every 10 ft. of center distance between shafts. If it is too loose, the belt will have an unsteady flapping motion which will injure both belt and machinery; if it is too tight, the bearings will be worn and the belt quickly destroyed.

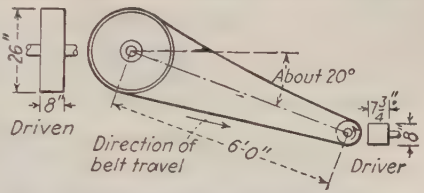


FIG. 153.—Typical sketch of belt layout. (*General Electric Co.*)

Vertical drives, the mounting of one pulley above another, should be avoided. This is particularly true where the lower pulley is the smaller. The effective tension and arc of contact are reduced in vertical drives so that the normal load cannot be carried. It is better if the angle of the belt with the floor does not exceed 45 deg. (see Fig. 154).

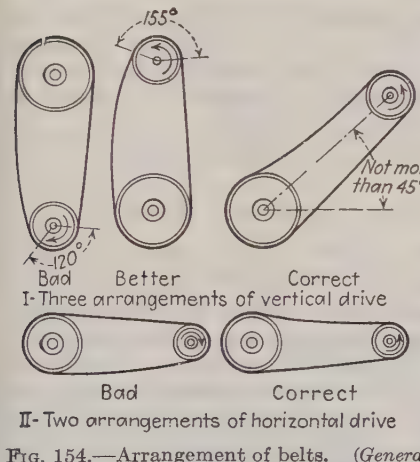


FIG. 154.—Arrangement of belts. (*General Electric Co.*)

Where several belts transmit power from a line shaft, it is advantageous, where possible, to locate the line shaft so that the bearing pressures can be equalized and reduced by alternating the direction of drive, first on one side, then on the other.

409. Rule for Finding Length of Belts.—When it is not feasible to measure wih the tapeline the length required, the following rule, which gives an accurate result when the pulleys are of the same diameter and an approximately accurate result when the pulleys are of different diameters, can be used:

Add the diameters of the two pulleys (D and d, Fig. 155) together, divide the result by 2 and multiply the quotient by 3¼; add the product to twice the distance L between the centers of the shafts, and the result is the length required. All values should be expressed either in feet or in

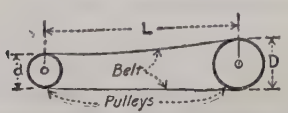


FIG. 155.—Notation for belt-length formula.

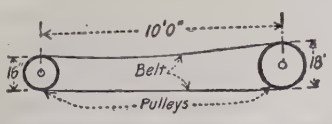


FIG. 156.—Example in finding belt length.

inches. Expressed as a formula, using the notation of Fig. 155, the rule becomes

$$\text{Length of belt} = [(D + d)1.57] + 2L \qquad (10)$$

Example.—What is the length of the belt required for the two pulleys of Fig. 156? Diameters of pulleys are 16 and 18 in. Distance between centers is 10 ft. or 120 in.

Solution.—Substitute in the formula

$$\text{Length of belt} = [(18 + 16)1.57] + 2 \times 120 = (34 \times 1.57) + 240 = 293.4 \text{ in.} = \frac{293.4}{12}$$

$$= 24.4 \text{ ft.}$$

If one pulley is considerably larger than the other a little extra allowance should be made, because the distance between the points of tangency of the belt on the two pulleys is somewhat greater than the exact distance between the centers of the shafts.

410. Rule for Measuring Belts in the Roll.—Add to the diameter of the roll in inches the diameter of the hole in the center of the roll. Multiply this sum by the number of coils in the roll and multiply this product by 1.32. The three figures on the left indicate the number of feet in the roll.

Example.—Roll of 5-in. single leather belt measure 37⅝ in. outside diameter; hole is 4⅝ in. in diameter; number of coils in roll is 84. How long is the belt?

Solution.—Using the above rule

$$(37\tfrac{5}{8} + 4\tfrac{5}{8}) \times 84 = 42\tfrac{1}{4} \times 84 = 3{,}549 \times 1.32 = 4{,}684.68$$

The first three figures on the left indicate that the roll contains 468½ ft. By actual measurement the roll is found to contain 469 ft. (Page Belting Co.)

411. Splicing Belts (Page Belting Co.).—Where possible, the ends of the belt should be fastened together by splicing and cementing. If belts are to be laced or fastened otherwise than with cement, cut off the ends perfectly true, using a try square. Punch the holes exactly opposite one another in the two ends as in Fig. 157. The grain side of the belt should be run next to the pulley, and the belt should be run off, not against, the laps. Undoubtedly, exclusive of cementing, lacing is the best method for fastening belt ends together, as the lacing is as flexible as the belt and runs noiselessly over the pulleys. The best lacing is in the end the cheapest. Cheap lacing is very expensive in the long run.

Use a small lace so that the holes will be small. For belts 1 to 2¼ in. wide, use ¼-in. lacing; 2½ to 4½ in., use 5/16-in. lacing; 5 to 12 in., use ⅜-in. lacing. For wider belts use wider lacing in proportion. Avoid thick lacing. Light, strong lacing is the best.

In punching a belt for lacing it is desirable to use an oval punch, the longer diameter of the punch lying parallel with the length of the belt, so that a minimum amount of leather across the belt will be cut out. There should be in each end of the belt two rows of holes, placed zigzag. Make the holes the smallest possible that will admit the lace. In a 2-in. belt there should be 3 holes in each end; in a 2½-in. belt, 4 holes; in a 3-in.

belt, 5 holes; in a 4-in. belt, 7 holes; in a 5-in. belt, 9 holes; in a 6-in. belt, 11 holes; in an 8-in. belt, 15 holes; in a 10-in. belt, 19 holes; in a 12-in. belt, 23 holes.

The center of no hole should come nearer to the side of the belt than $\frac{5}{8}$ in. or nearer the end than $\frac{7}{8}$ inch. The second row should be at least

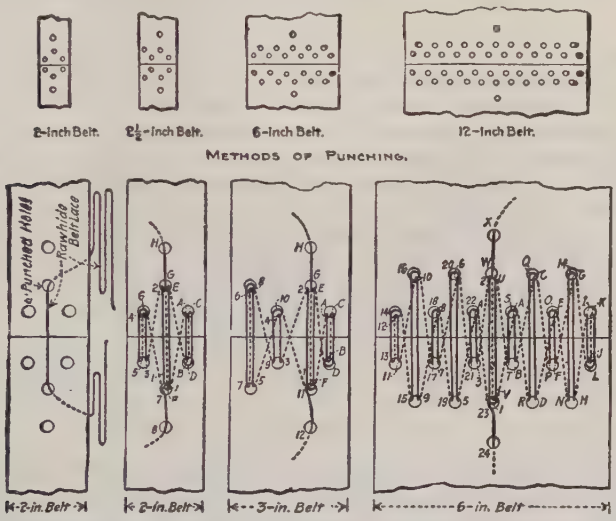


FIG. 157.—Method of lacing belts.

$1\frac{3}{4}$ in. from the end. On wide belts these distances should be even a little greater.

Begin to lace in the center of the belt and take great care to keep the ends exactly in line and to lace both sides with equal tightness. The lacing positively must not be crossed on the side of the belt that runs next to the pulley.

412. In putting on new belts, a common rule is to draw them up and stretch them $\frac{1}{8}$ in. for every foot in length of belt.

The strongest part of belt leather is near the flesh side, about one-third the way through from that side. It is, therefore, desirable to run the grain (hair) side on the pulley, in order that the strongest part of the belt may be subject to the least wear. The flesh side is not so apt to crack as is the grain side when the belt is old; hence it is better to crimp the grain than to stretch it. Leather belts run with the grain side to the pulley will drive 30 per cent more than if run with the flesh side. The belt, as well as the pulley, adheres best when smooth, and the grain side adheres best because it is smoother.

413. A belt adheres much better and is less apt to slip when run at a high speed than at a low speed. Therefore, it is better to gear a mill with small pulleys and run them at high velocity, than with large pulleys and run slower. A mill thus geared costs less and has a much neater appearance than with large, heavy pulleys.

414. Belt Troubles.—The belt on any belt-connected machine should be tight enough to run without slipping, but the tension should not be too great, or the bearings will heat. The crowns of driving and driven pulleys should be alike, as "wobbling" of belts is sometimes caused by pulleys having unlike crowns. If this is caused by bad joints, they should be broken and cemented over again. A wave motion or flapping is usually caused by slippage between the belt and pulley, resulting from grease spots, etc. It may, however, be a warning of an excessive overload.

This fault may sometimes be corrected by increasing the tension, but a better remedy is to clean the belt. A back and forth movement on the pulley is caused by unequal stretching of the edges of the belt. If this does not cure itself shortly, examine the joints. If they are evenly made and remain so, the belt is bad and should be discarded.

415. Gear Drive.—Gearing is the most positive form of power transmission and is frequently employed when the motor can be mounted directly on a machine. The points to be considered on a gear drive are the following: (1) speed reduction, (2) pitch of the gears, (3) number of teeth on the gears (pinion and gear), (4) face of the gear, (5) pitch-line speed, (6) distance between centers, (7) use of idler gears, and (8) mounting of the motor.

The speed reduction is the same as for the belt drive. Each motor rating has a minimum pinion to limit stresses to safe values. The pitch, number of teeth, and face for motor pinions have been standardized for back-geared motors, and the best practice when gearing a motor directly to machines is to use these motor pinions if possible. Table 426 gives the standard motor ratings and other valuable gearing information. (The information on gear drives given herein is largely from an article in the *American Machinist*, by A. G. Popcke.)

416. The method of gearing depends largely upon the distance between centers and the space available for the motors. In all cases the pinion

must not be selected smaller than the minimum specified in Sec. **426.** The pitch-line speed must not exceed the limits given. There are two general cases covering the mounting of a motor to drive a machine through gears; these are:

1. Where the dimension of the motor or machine limits the distance between centers of the motor shaft and the driven shaft.

2. Where the limitation of (1) does not exist.

The first case occurs when a motor is mounted on top, side, or bottom of a machine, as shown in Fig. 158. The dimension causing limitations

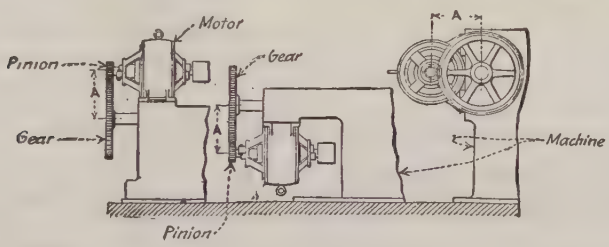


FIG. 158.—Motor mountings for gear drive (distances between gear centers limited).

is indicated by *A* in these illustrations. The proper distance can be obtained by using large enough gears; the limit is pitch-line speed. An intermediate idler gear frequently overcomes the difficulties here experienced.

In the second case the relation of the motor and machine is shown in Fig. 159. In this case the motor can be mounted on a base, and the motor pinion can mesh with the gear on the machine in any convenient position.

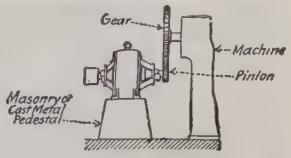


FIG. 159.—Motor mounting for gear drive (no limitation to center distance).

If reductions greater than 7:1 are required, it is usually necessary to obtain the reduction by the use of two sets of gears. The back-geared motors discussed under Belt Drive can be used to furnish one set of gears in these cases. Thus if a reduction of 10:1 is desired, a back-geared motor with a standard 6:1 reduction, with a further reduction from the countershaft of the motor to the machine of $1\frac{2}{3}$:1 or 1.66:1 will fulfill the requirements

Example.—The speed of the driven shaft of the machine is 210 r.p.m., the hp. is 10, the motor is mounted on the machine, and the limiting distance between centers is 12 in. What are the sizes of gear and pinion to be used? The machine is a punch and shear.

Solution.—In this case a pitch-line speed of approximately 1,000 ft. per min. will be employed. Table 426 shows that a 10-hp. motor at 850 r.p.m. is the highest speed

motor that can be used for this pitch-line speed. The ratio of reduction is then

$$\frac{850}{210} = 4.05 \text{ (use 4:1)}$$

The distance between centers for any set of gears is determined by the formula

$$a = \frac{b}{2P} \qquad \text{(inches)} \quad (11)$$

where a = the distance between centers in inches; b = the sum of the number of teeth in both gears; and P = the diametral pitch. In this case

$$a \text{ or } 12 = \frac{b}{2 \times 5}; \qquad b = 120$$

The number of teeth in the pinion is,

$$\frac{b}{\text{Ratio of reduction plus 1}} = \frac{120}{5} = 24 = \text{number of teeth}$$

The number of teeth in the gear is $4 \times 24 = 96$.

Table 428 shows that the pitch-line speed for this motor with 20 teeth is 890 ft. per min. The pitch-line speed with 24 teeth is

$$\frac{24}{20} \times 890 = 1{,}068 \text{ ft. per min.}$$

If quiet operation is desired a cloth or rawhide pinion should be used with a 3¾-in. face. Thus the gears are specified as follows:

Motor pinion—rawhide—P = 5, face 3¾ in., 24 teeth. Machine gear—steel P = 5, face 3 in., 96 teeth.

The bore for each is determined by the diameter of the shaft to which it is connected. The pinion is wider than the gears, so that the rawhide only engages with the gear. If it were the same width, the brass endplates of the rawhide pinion would engage with the gear, causing noise.

417. In the selection or specification of pinions for motors (C. W. Drake, *Electric Journal*) for geared applications, three dimensions must be determined, namely, the face, the diameter, and the pitch. These dimensions vary symmetrically according to the strength required, or, in other words, according to the torque exerted in transmitting power. As the horsepower and speed of the motor in any case determine the torque, it is evident these are the factors determining the proper dimensions of a pinion for the motor. A line of pinions with dimensions increasing symmetrically with the torque will therefore answer the purpose for all combinations of horsepower and speed. Every geared application requires special consideration, since the nature of the service, the shaft diameter, etc., may affect the dimensions of the pinion.

In gear drive the pinion is subject to most rapid wear owing to its smaller diameter. It is as important to have a pinion of good wearing qualities as it is to have one of sufficient strength, and, for a pinion of a given material, the ability to withstand wear depends mainly, if not wholly, on the width of the face. With a steel pinion and a cast-iron

gear the former is usually the limiting factor of life and the latter the limiting factor of strength.

418. Cast-steel gears are about twice as strong as cast iron and should be used when the face of a corresponding cast-iron gear would be 4.5 in. or more, although the cost is approximately double that of cast-iron. With continuous contact all along the length of the teeth, the strength of the gear is approximately proportional to the face and the square of the circular pitch, but gear teeth seldom make such contact until worn down in service. With new gears the whole pressure is brought to bear on the high spots, and stripping may occur before they are worn down; hence the necessity of using the stronger material.

419. Bronze and Rawhide Pinions.—For equal strength the working face of rawhide pinions must be about 25 per cent wider than corresponding steel pinions. For quiet operation, only the rawhide should be in contact with the gear, although for high-torque motors and other severe service the gears may be widened to cover the entire pinion, thus making use of the metal flanges. Where steel pinions would make objectionable noise, rawhide pinions should be used if the stresses permit, since the pitch-line speed with a rawhide pinion is limited more by the rapid wear of the pinion than by noise. A pitch-line speed of 2,000 ft. per min. is considered a fair average limit for rawhide, but 2,500 to 3,000 ft. per min. may be used under especially favorable conditions regarding attendance, lubrication, absence of moisture, or high temperature and for intermittent service or where the life of the pinion is not important.

The wear and noise of bronze pinions are intermediate between those of rawhide and steel. Bronze pinions are particularly adapted to conditions where heat and moisture prohibit the use of rawhide. Their cost is about the same as rawhide.

420. Noise of Gears and Pitch-line Speed Limits.—Spur gears ordinarily begin to make a noticeable noise at pitch-line speeds of about 600 ft. per min., but under average conditions may not become disagreeably noisy with pitch-line speeds under 1,200 ft. per min. The amount of noise allowable depends on the noise made by surrounding machinery, on the character of the workmen, and on the nature of the work in the vicinity. A noise that would be unnoticeable in a boiler shop might be exceedingly disagreeable in a shop that was otherwise comparatively quiet. Where noise is not a limiting feature there is no limit to allowable pitch-line speeds, except the increased wear and depreciation of the motor, gears, and driven machine; but depreciation may become a very important factor with high pitch-line speeds, say 2,500 ft. per minute, or sometimes even less. Tests recently made to determine a design for gears that will give the least noise and yet have sufficient strength and wearing qualities indicate the following facts, other conditions being the same:

1. Gears having large teeth give forth a relatively greater volume of noise at a low pitch that does not carry far, while gears having smaller teeth give forth a smaller volume of noise at a higher pitch that carries farther.

2. Most of the noise comes from the gear and not from the pinion or the motor.

3. A gear designed so that it will give a dead sound when struck a blow with the hammer will be the least noisy in operation.

421. Conditions for Noiseless Operation of Gears.—Rigid and massive supports and close-fitting bearings for both the motor and the driven machine are conducive to a noiseless gear drive, and the pinion should always be placed close to the motor bearing. A gear application with motor mounted upon the ceiling might be twice as noisy as the same application with motor mounted on a concrete foundation.

422. Pinions for High-torque Motors.—For series motors and those heavily compounded, as bending-roll motors, or for motors subject to very severe service of any kind, select a pinion suitable for a constant-speed motor of the same rated r.p.m. but of about 50 per cent higher horsepower.

423. Selection of Ratio for Back-geared Motors.—A ratio of about 6:1 is usually standard for back-geared motors and should be selected wherever possible, but smaller ratios down to 3:1 or maximum ratios up to 7:1 may be obtained in certain capacities of motors for service where the conditions of the application warrant the use of such ratios (see preceding paragraphs on this subject).

424. Outboard Bearings for Gear Drive.—Outboard bearings should be used for motors of about 40 hp. and above in heavy geared service requiring continuous operation with frequent reversing and overloads; also for all motors of about 100 hp. and above in any geared service. The proper use of outboard bearings cannot be emphasized too strongly, since on account of increased expense there is a tendency to omit them even where good engineering demands their use.

425. How to Use the Chart for Determining Gear Dimensions (C. W. Drake, *Electric Journal*).—The dimensions for pinions for average conditions of motor-drive service are given in Fig. 160. This chart is useful in making preliminary estimates or selections of pinions for geared motors. The chart applies without correction **to steel pinions only.** The diameters are considered about standard for the various ratings, although both smaller and larger pinions can generally be used, the limiting size for small pinions being the strength and number of teeth, and, for large pinions, the pitch-line speed.

Example.—To determine the steel pinion for a 5-hp. motor at 1,200 r.p.m., find the intersection of the oblique line marked 5 hp. with the horizontal line through 1,200 r.p.m. On the vertical line through this intersection may be found 21.9-lb. torque, 2.3-in. pinion

face, 3.2-in. pitch diameter, and a diametral pitch of 4.85. A 2.25-in. pinion face is good practice here, since pinion-face dimensions with fractions smaller than 0.25 in. are not commonly used. The diametral pitch is also usually a whole number, except for very

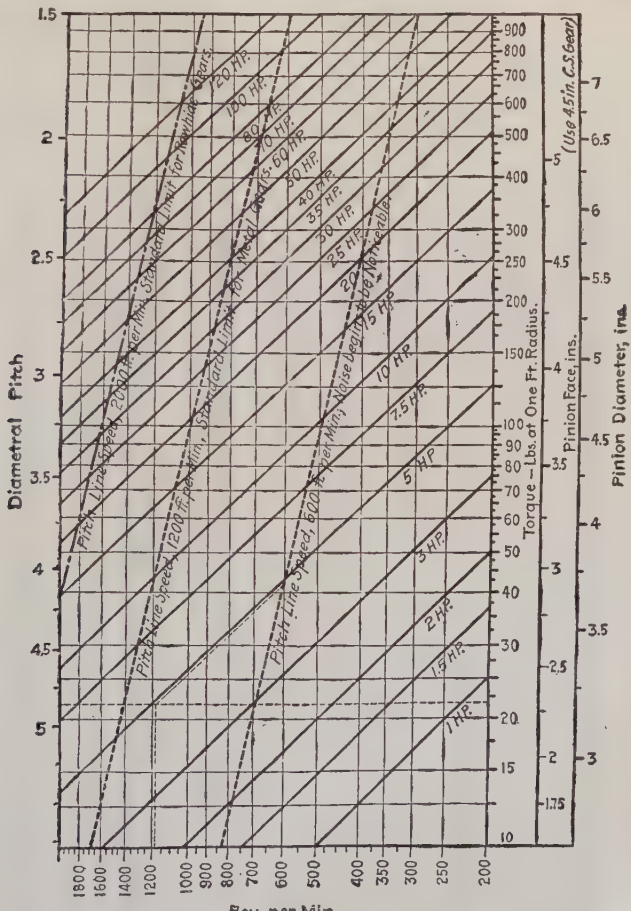


FIG. 160.—Chart for determining approximate commercial values of pinion diameter, pinion face, diametral pitch, pitch-line speed, and torque, with revolutions per minute and horsepower of motor given.

large pinions, where half pitches are sometimes used, so that a pitch of 5 would probably be used in the above case. Since the number of teeth is the product of the pitch diameter and the diametral pitch, the assumed pitch diameter, 3.2 in., is satisfactory with the 5 pitch, because it gives a whole number of teeth; *i.e.*, 16.

426. Gear Data For Motor Applications

(A. G. Popcke, *American Machinist*)

Hp.	R.p.m.	Diam. pitch	Number of teeth			Face		Standard pitch-line speed	Min. diam.	Max. no. of teeth for pitch line speed of	
			Standard pinion	Min. raw-hide pinion	Min. steel pinion	Steel	Raw-hide and cloth			1,000 ft. per min.	2,000 ft. per min.
1	1,700	8	17	15	13	1	1½	940	1.63	18	36
1	1,200	8	17	15	13	1½	2	665	1.63	25	50
2	1,700	8	17	15	13	1½	2	940	1.63	18	36
2	1,200	8	22	20	19	1¾	2¼	870	2.38	25	50
2	850	6	18	21	19	1¾	2¼	615	2.38	36	72
3	1,800	8	22	20	19	1¾	2¼	1,300	2.38	..	34
	1,150	8	22	21	19	1¾	2¼	830	2.38	26	52
	850	6	18	18	18	2¾	3⅜	670	3.0	27	54
5	1,800	8	22	21	19	1¾	2¼	1,300	2.38	..	34
	1,200	6	18	18	18	2¾	3⅜	940	3.0	19	38
	850	6	21	19	18	2¾	3⅜	990	3.0	27	54
7½	1,700	6	18	18	18	2¾	3⅜	1,400	3.0	..	26
	1,150	6	21	19	18	2¾	3⅜	1,050	3.0	20	40
	975	5	19	18	18	3	3¾	970	3.6	19	38
	850	5	19	18	18	3	3¾	850	3.6	22	44
	650	5	20	18	18	3	3¾	685	3.6	29	58
10	1,700	6	21	19	18	2¾	3⅜	1,420	3.0	..	27
	1,300	6	22	19	18	2¾	3⅜	1,250	3.0	..	35
	1,150	5	19	18	18	3	3¾	1,150	3.6	..	33
	850	5	20	18	18	3	3¾	890	3.6	22	44
	730	5	21	18	18	3½	4¼	805	3.6	26	52
	600	5	21	19	19	3½	4¼	665	3.8	31	62
15	1,700	5	19	18	18	3	3¾	1,700	3.6	..	22
	1,250	5	20	18	18	3	3¾	1,300	3.6	..	30
	1,150	5	21	18	18	3½	4¼	1,210	3.6	..	35
	825	5	21	19	19	3½	4¼	910	3.8	23	46
	675	4½	22	18	18	4	5	870	4.0	25	50
	600	4½	22	19	19	4	5	770	4.22	29	58
20	1,700	5	20	18	18	3	3¾	1,780	3.6	..	22
	1,100	5	21	19	19	3½	4¼	1,220	3.8	..	35
	900	4½	22	18	18	4	5	1,150	4.0	19	38
	750	4½	22	19	19	4	5	960	4.22	23	46
	650	4	21	18	18	4¼	5¼	890	4.5	23	46
25	1,400	5	21	19	19	3½	4¼	1,550	3.8	..	27
	1,100	4½	22	18	18	4	5	1,400	4.0	..	31
	950	4½	22	19	19	4	5	1,220	4.22	..	36
	825	4	21	18	18	4¼	5¼	1,130	4.5	18	36
	600	4	22	19	18	4½	5½	860	4.5	25	50
30	1,700	5	21	19	19	3½	4¼	1,880	3.8	..	22
	1,150	4½	22	19	19	4	5	1,470	4.22	..	30
	975	4	21	18	18	4¼	5¼	1,330	4.5	..	31
	725	4	22	19	18	4¼	5¼	1,050	4.5	21	42
	600	3¼	20	..	18	4½	...	970	5.53	20	40
35	1,700	4½	22	18	18	4	5	2,180	4.0	..	20
	1,150	4	21	18	18	4¼	5¼	1,580	4.5	..	27
	850	4	22	19	18	4¼	5¼	1,220	4.5	18	36
	675	3¼	20	..	18	4½	...	1,080	5.53	18	36
40	1,700	4½	22	19	19	4	5	2,180	4.22	..	20
	950	4	22	19	18	4¼	5¼	1,370	4.5	..	32
	775	3¼	20	..	18	4½	...	1,250	5.53	..	32
	600	3	18	..	15	4½	...	940	5.0	19	38
50	1,700	4	21	18	18	4¼	5¼	2,340	4.5	..	18
	975	3¼	20	..	18	4½	...	1,580	5.53	..	25
	750	3	18	..	15	4½	...	1,170	5.0	15	30
	565	3	20	..	18	4½	...	990	6.0	20	40

427. Adjustable-speed Motor Ratings and Pulley and Gear Data For Use When Connecting Adjustable-speed Motors to Drive Machinery

(A. G. Popcke, *American Machinist*)

Hp.	R.p.m.		Smallest pulley		Gear data					Pitch-line speed, at min. diam.		Max. teeth not to exceed 2,000 ft. per min. at max. speed
						Face						
	Min.	Max.	Diam.	Face	Pitch	Steel	Rawhide	Min. teeth	Min. diam.	Min. speed	Max. speed	
1	740	2,200	3	3	8	1¾	2¼	19	2.38	460	1,380	27
	600	1,800	3	3	8	1¾	2¼	19	2.38	375	825	46
	450	1,800	3	4	8	1¾	2¼	19	2.38	280	1,120	34
2	1,100	2,200	3	3	8	1¾	2¼	19	2.38	690	1,380	27
	740	2,200	3	4	8	1¾	2¼	19	2.38	460	1,380	27
	450	1,800	4	4½	6	2¾	3⅜	18	3.0	355	1,420	25
3	1,000	2,000	3	4	8	1¾	2¼	19	2.38	625	1,250	30
	660	2,000	4	4½	6	2¾	3⅜	18	3.0	520	1,560	23
	450	1,800	4½	5	6	2¾	3⅜	18	3.0	355	1,422	25
	375	1,500	5	6	6	2¾	3⅜	18	3.0	294	1,176	30
5	1,000	2,000	4	4½	6	2¾	3⅜	18	3.0	790	1,580	23
	750	1,500	4½	5	6	2¾	3⅜	18	3.0	590	1,180	30
	600	1,800	5	6	6	2¾	3⅜	18	3.0	470	1,410	25
	450	1,800	6	7	5	3	3¾	18	3.6	425	1,700	21
	375	1,500	6	7½	5	3½	4¼	18	3.6	355	1,420	25
7½	900	1,800	5	6	6	2¾	3⅜	18	3.0	705	1,410	25
	800	1,600	5	6	5	3	3¾	18	3.6	755	1,510	24
	600	1,800	6	7	5	3	3¾	18	3.6	570	1,710	21
	500	1,500	6	7½	5	3½	4¼	18	3.6	475	1,425	25
	450	1,800	6½	9	5	3½	4¼	19	3.8	450	1,800	21
	350	1,400	6½	9	5	3½	4¼	19	3.8	350	1,400	27
10	850	1,700	6	7	5	3	3¾	18	3.6	800	1,600	22
	750	1,500	6	7	5	3	3¾	18	3.6	710	1,420	25
	600	1,800	6	7½	5	3½	4¼	18	3.6	570	1,710	21
	500	1,500	6½	9	5	3½	4¼	19	3.8	500	1,500	25
	450	1,800	6½	9	5	3½	4¼	19	3.8	450	1,800	21
	375	1,500	7	8	4½	4	5	18	4.0	390	1,560	23
15	780	1,560	6½	9	5	3½	4¼	19	3.8	780	1,560	24
	600	1,200	7	8	4½	4	5	18	4.0	630	1,260	28
	500	1,500	7½	9½	4½	4	5	19	4.22	555	1,665	23
	400	1,200	8	9½	4	4¼	5¼	18	4.5	470	1,410	25
	375	1,500	9	10½	4	4¼	5¼	18	4.5	440	1,760	20
20	650	1,300	7½	9½	4½	4	5	19	4.22	720	1,440	26
	550	1,100	8	9½	4	4¼	5¼	18	4.5	645	1,290	28
	500	1,500	9	10½	4	4¼	5¼	18	4.5	590	1,770	20
	400	1,200	10	11	3¼	4½	...	18	5.53	580	1,740	21
	300	1,200	12	13	3	4½	...	15	5.0	390	1,560	19
25	550	1,100	9	10½	4	4¼	5¼	18	4.5	645	1,290	28
	400	1,200	12	13	3	4½	...	15	5.0	525	1,575	19
	300	1,200	12½	15	3	4½	...	18	6.0	470	1,880	19
30	550	1,100	10	11	3¼	4½	...	18	5.53	800	1,600	23
	350	1,050	12½	15	3	4½	...	18	6.0	550	1,650	22
	250	1,000	14	18	3	4½	...	18	6.0	390	1,560	23
40	550	1,100	12	13	3	4½	...	15	5.0	720	1,440	21
	350	1,050	12½	15	3	4½	...	18	6.0	550	1,650	22
	250	1,000	16	21	3	4½	...	19	6.33	415	1,660	23
50	500	1,000	12½	15	3	4½	...	18	6.0	790	1,580	23
	325	975	16	21	3	4½	...	19	6.33	540	1,620	23

428. Gearing Definitions and Formulas.—A circle whose circumference passes through the point of contact on each tooth of a gear or pinion when this point is on the line connecting the centers of the two wheels is called

the **pitch circle.** The diameter of this circle is the **pitch diameter**, and its circumference is the **pitch line.**

Diameter, when applied to gears, is always understood to mean the pitch diameter.

Diametral pitch is the number of teeth to each inch of the pitch diameter. To illustrate: if a pinion has 18 teeth and the pitch diameter is 3 in., there are 6 teeth to each inch of the pitch diameter, and the diametral pitch is 6.

Circular pitch is the distance from the center of one tooth to the center of the next, measured along the pitch line.

In the following formulas, for use in gear problems:

d^1 = pitch diameter of pinion
d = outside diameter of pinion
p = circular pitch
p^1 = diametral pitch
S = distance between centers $= \frac{1}{2}(D^1 + d^1)$
D^1 = pitch diameter of gear
D = outside diameter of gear
n = number of teeth on pinion
N = number of teeth on gear
r = gear ratio $= \frac{N}{n} = \frac{D^1}{d^1} = \frac{D}{d}$

$\pi = 3.1416$

$$p = \frac{\pi}{p^1} = \frac{\pi d}{n+2} \quad (12) \qquad d^1 = \frac{2S}{r+1} \quad (17)$$

$$p^1 = \frac{\pi}{p} = \frac{n+2}{d} \quad (13) \qquad D^1 = \frac{2\,Sr}{r+1} \quad (18)$$

$$n = d^1p^1 = \frac{\pi d^1}{p} = dp^1 - 2 \quad (14) \qquad n = \frac{2Sp^1}{r+1} \quad (19)$$

$$p^1 = \frac{n}{d^1} \quad (15) \qquad N = \frac{3Sp^1 r}{r+1} \quad (20)$$

$$S = \frac{N+n}{2p^1} \quad (16) \qquad S = \frac{d^1(r+1)}{2} \quad (21)$$

429. Gear and Belt Drives for Adjustable-speed Motors.—Table 426 deals with constant-speed motors. Adjustable-speed motor problems are solved similarly. The belt speeds and pitch-line speeds must be carefully considered at the maximum speeds of the motors. The minimum pulleys and pinions are determined by the minimum speeds of the motors. Table 427 gives the ratings commonly used and pulley and gear information.

430. The design of chains is more complicated than that of belts and gears and it is, therefore, best to let the various chain manufacturers specify the chain, giving them the necessary information. The minimum sprocket to be used on a motor is the same as the minimum pinion given in Table 426. Chain speed should not exceed 1,200 to 1,600 ft. per min. The best practice does not exceed 1,000 ft. per min. For factors that must be considered see Sec. **315.**

MOTOR CIRCUITS

431. The National Electrical Code rules definitely specify certain requirements with respect to the size and location of the component parts of motor branch circuits. The following tables and rules are in accordance with the 1951 edition of the Code. Certain cities have adopted motor wiring tables and rules which may be more exacting than those required by the Code. In such communities these local requirements should be followed in preference to the tables presented herein.

In the following sections the terminology of the National Electrical Code with respect to **within sight** is adhered to. A distance of more than 50 ft. is considered equivalent to being **out of sight,** even though there may be no obstructions between the two points.

Full-load Motor Currents.—According to the National Electrical Code, whenever the current rating of a motor is used to determine the current-carrying capacity of conductors, switches, branch-circuit overcurrent devices, etc., the values given in Tables 6 to 9 of Div. 11, including footnotes, should be used in lieu of the actual current rating marked on a motor name plate. Motor-running overcurrent protection should be based on the motor name-plate current rating. If a motor is marked in amperes but not in horsepower, the horsepower rating should be assumed to be that corresponding to the value given in Tables 6 to 9 of Div. 11, prorated if necessary.

432. Types of Motor Branch Circuits.—Branch circuits supplying motors as required by the National Electrical Code may be divided into three types, as follows: (1) a branch circuit supplying only a single motor, (2) a branch circuit supplying several motors but no other equipment except that directly associated with the motors, and (3) a branch circuit supplying one or more motors and/or lamps and receptacles. Except when special requirements are met, as stated below, branch motor circuits must be of type 1, *i.e.*, each motor must be supplied with power by its own individual branch circuit.

Type 2 Branch Motor Circuits.—A branch circuit may supply two or more motors but no other equipment except that directly associated with the motors only when the following conditions 1 or 2 are fulfilled:

1. Two or more motors each not exceeding 1 hp. in rating and each having a full-load rated current not exceeding 6 amp. may be supplied from a single branch circuit protected at not more than 20 amp. at 125 volts or less, or 15 amp. at 600 volts or less. Individual running overcurrent protection for each motor is not required.

2. Two or more motors of any ratings, each having individual running overcurrent protection, may be connected to one branch circuit, provided that all the following conditions are complied with:

a. Each motor-running overcurrent device must be approved for group installation.

b. Each motor controller must be approved for group installation.

c. The branch circuit must be protected by fuses having a rating equal to that specified in Tables 12 to 14 of Div. 11 for the largest motor connected to the branch circuit plus an amount equal to the sum of the full-load current ratings of all other motors connected to the circuit.

d. The branch-circuit fuses must not be larger than allowed by Sec. **442** for the thermal cutout or relay protecting the smallest motor of the group.

e. The conductors of any tap supplying a single motor need not have individual branch-circuit protection, provided that they comply with either of the following: (1) no conductor to the motor shall have a current-carrying capacity less than that of the branch-circuit conductors, or (2) no conductor to the motor shall have a current-carrying capacity less than one-third that of the branch-circuit conductors, with a minimum in accordance with Sec. **444,** the conductors to the motor-running protective device being not more than 25 ft. long and being protected from mechanical injury.

Type 3 Branch Motor Circuits.—One or more motors may be connected to a branch circuit which also supplies lamps and/or receptacles only when the following conditions 1 or 2 are fulfilled.

1. Two or more motors each not exceeding 1 hp. in rating and each having a full-load rated current not exceeding 6 amp. may be supplied by a branch circuit protected at not more than 20 amp. at 125 volts or less, or 15 amp. at 600 volts or less. Individual running current protection for each motor is not required.

If a motor is connected to a branch circuit by means of a plug and receptacle, the rating of the plug and receptacle shall not exceed 15 amp. at 125 volts or 10 amp. at 250 volts.

The overcurrent device protecting a branch circuit to which a motor or motor-operated appliance is connected shall have sufficient time delay to permit the motor to start and accelerate its load.

2. Motors of larger ratings than specified in paragraph 1 may be connected to branch circuits which also supply lamps and/or receptacles only if provided with individual running overcurrent protection selected to protect the motor as specified in Sec. **436.** Both the controller and the motor-running overcurrent device shall be approved for group installation with the protective device of the branch circuit to which the motor is connected.

The overcurrent device protecting a branch circuit to which a motor or motor-operated appliance is connected shall have sufficient time delay to permit the motor to start and accelerate its load.

If a motor is connected to a branch circuit by means of a plug and receptacle, the running overcurrent device must be an integral part of the motor or of the appliance.

433. The component parts of a motor branch circuit for an individual motor are shown in Fig. 161.

P_1—Overload Protective Device in Feeder or Main.—May consist of fuses or circuit breaker. Refer to Sec. **447.**

SB—Branch-circuit Switch.—Not required by National Electrical Code rules. May consist of switch or circuit beaker. If switch is used, must have fuse clips large enough to accommodate fuses required at P_2. If circuit breaker is used for branch-circuit overload protective device, it will serve double purpose of branch-circuit switch and overload protective device. Refer to Sec. **443.**

P_2—Branch-circuit Overload Protective Device.—May consist of fuses or circuit breaker. If circuit breaker is used, it will serve the double purpose of branch-circuit switch and overload protective device. Refer to Sec. **442.**

SM—Motor Switch.—May consist of switch or circuit breaker. Must have a continuous-duty rating of at least 115 per cent of the motor full-load current. For motors of 50 hp. and under, and for all cases when switch is used for shutting down the motor, switch must be of the motor-circuit type. If the switch is fused, the fuse clips must be large enough to accommodate size of fuses required at P_3. Switch S_M in Diagram III must be either located within sight of the motor or arranged so that it may be locked in the open position. If switch S_M is of the two-throw or two-position type (Diagram II) for cutting the motor overload protective device out of the circuit during the starting period, the switch must be so arranged that it cannot be left in the starting position. If circuit breaker is used for motor overload protective device, it will serve the double purpose of motor switch and protective device. Refer to Sec. **440.**

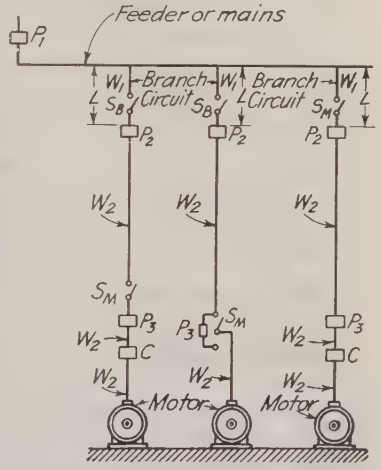


FIG. 161.—Single-line diagrams giving requirements for component parts of branch motor circuits with branch-circuit overload protection.

P_3—Motor Overload Protective Device.—May consist of fuses, thermal cutouts, thermal relays, magnetic relays, or circuit breaker. Generally not required for intermittent-duty motors. Rating or setting must not be greater than 125 per cent of the motor full-load current except when this value does not coincide with any standard rating. Then the next larger standard size may be employed. The motor overload protective device is generally incorporated in the controller *C* and mounted inside the controller case. Refer to Secs. **436** to **439.**

C—Motor Controller.—Refer to Sec. **435.**

W_1—Branch-circuit Tap Wires from Point of Connection to Feeder to Branch-circuit Overload Protective Device.—If branch-circuit overload protective device is located at point of connection to feeder, the carrying capacity of tap wires must be at least 125 per cent of the motor full-load current. If the length *L* of the wires from the point of connection to the feeder to the branch-circuit overload protective device is 25 ft. or less, the carrying capacity of the tap wires must be at least one-third of the carrying capacity of the feeder. If the length *L* of the wires from the point of connection to the feeder to the branch-circuit overload protective device is greater than 25 ft., the tap wires must be of the same size as the feeder.

W_2—Branch-circuit Wires from Branch-circuit Overload Protective Device to Motor. Must have carrying capacity of at least 125 per cent of motor full-load current for continuous-duty motors. Refer to Sec. **444.**

434. The component parts of a motor branch circuit supplying several motors are shown in Fig. 162.

P_1—Overload Protective Device in Branch Circuit.—May consist of fuses or circuit breaker. If motor overload protective device consists of thermal cutouts or thermal relays, the rating of the fuses or setting of the circuit breaker must not be greater than four times the full-load current of smallest motor unless the motor overload protective device is approved for group fusing. If the motor overload protective device is approved for group fusing the rating of the fuses or setting of circuit breaker must not exceed the maximum allowable rating marked on thermal cutout or thermal relay of smallest motor fed from main.

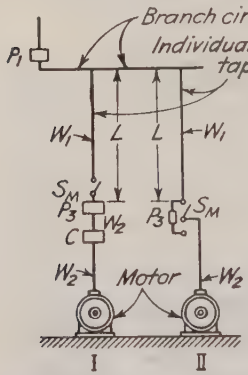


FIG. 162.—Single-line diagrams giving requirements for motor circuits when branch-circuit overload protective device is omitted.

If the motor overload protective devices are cut out during the starting period, P_1 must consist of fuses rated or time-limit circuit breakers set at not more than 400 per cent of the full-load current of smallest motor so protected. Refer to Sec. **442.**

SM—Combined Motor and Branch-circuit Switch.—May consist of switch or circuit breaker. Must have a continuous-duty rating of at least 115 per cent of the motor full-load current. For motors of 50 hp. and under, and for all cases when switch is used for shutting down the motor, switch must be of the motor-circuit type. If switch is fused, the fuse clips must be large enough to accommodate the size of fuses required at P_3. If switch is used for shutting down motor, switch must be located as close as possible to motor and its driven machinery, and in the most accessible location for operator. If switch is not used for shutting down motor, it may be located remote from motor, provided that it is either located within sight of motor or so arranged that it may be locked in the open position. If switch is of the two-position or double-throw type (Diagram II) for cutting the motor overload protective device out of the circuit during the starting period, the switch must be so arranged that it cannot be left in the starting position. If circuit breaker is used for motor overload protective device, it will serve double purpose of switch and overload protective device. Refer to Sec. **443.**

P_3—Motor Overload Protective Device.—May consist of fuses, thermal cutouts, thermal relays, magnetic relays, or circuit breaker. Must be approved for group installations. Rating or setting must not be greater than 125 per cent of the motor full-load current except when this value does not coincide with any standard rating, when the next larger standard size may be employed. The motor overload protective device is generally incorporated in the controller C and mounted inside the controller case. Refer to Secs. **436** to **439.**

C—Motor Controller.—Refer to Sec. **435.**

W_1—Individual Motor Tap Wires from Point of Connection to Branch Circuit to Motor Overload Protective Device.—If motor overload protective device is located at point of connection to the branch circuit, the carrying capacity of wires must be at least 125 per cent of the motor full-load current. If the length L of the wires is 25 ft. or less, the carrying capacity of the wires must be at least one-third of the carrying capacity of the branch-circuit wires. If the length L of the wires is greater than 25 ft., the wires must be of the same size as the branch circuit wires.

W_2—**Branch-circuit Wires from Motor Overload Protective Device to Motor.**—Must have a carrying capacity of at least 125 per cent of motor full-load current for continuous-duty motors. Refer to Sec. **444.**

435. Motor Controllers.—Each motor must be provided with a suitable controller that will be capable of starting and stopping the motor and of performing any other control functions that are required for the satisfactory operation of the motor, such as speed control. The different types of motor-control equipment are discussed in Secs. **235** to **301.** A controller for an a-c motor must be capable of interrupting the current of the motor under stalled-rotor conditions. Each motor must have its own individual controller except that, for motors of 600 volts or less, a single controller may serve a group of motors under any one of the following conditions:

1. If a number of motors drive several parts of a single machine or piece of apparatus such as metal and woodworking machines, cranes, hoists, and similar apparatus.

2. If a group of motors is under the protection of one overcurrent device as permitted in paragraph 1 of Sec. **432.**

3. If a group of motors is located in a single room within sight from the controller location.

A distance of more than 50 ft. is considered equivalent to being out of sight.

The controller must have a horsepower rating that is not less than that of the motor, except as follows:

1. Stationary Motor of ⅛ Hp. or Less. For a stationary motor rated at ⅛ hp. or less that is normally left running and is so constructed that it cannot be damaged by overload or failure to start, such as clock motors and the like, the branch-circuit overcurrent device may serve as the controller.

2. Stationary Motor of 2 Hp. or Less. For a stationary motor rated at 2 hp. or less, and 300 volts or less, the controller may be a general-use switch having an ampere rating at least twice the full-load current rating of the motor.

3. Portable Motor of ⅓ Hp. or Less. For a portable motor rated at ⅓ hp. or less, the controller may be an attachment plug and receptacle.

4. Circuit Breaker as Controller. A branch-circuit circuit breaker, rated in amperes only, may be used as a controller. When this circuit breaker is also used for overcurrent protection, it shall conform to the appropriate provisions of this section governing overcurrent protection.

A controller need not open all conductors to the motor unless it serves as a disconnecting means or unless one pole of the controller is placed in a permanently grounded conductor.

Machines of the following types shall be provided with speed-limiting devices, unless the inherent characteristics of the machines, the system, or the load and the mechanical connection thereto are such as to safely

limit the speed, or unless the machine is always under the manual control of a qualified operator.

1. Separately excited d-c motors.

2. Series motors.

3. Motor-generators and converters that can be driven at excessive speed from the d-c end, as by a reversal of current or decrease in load.

Adjustable-speed motors, if controlled by means of field regulation, shall be so equipped and connected that they cannot be started under weakened field, unless the motor is designed for such starting.

The controller for a motor should be located as near as possible to the motor in order to make the length of the control wires between the controller and the motor as short as possible. The point from which the motor is controlled should be located as close as is feasible to the motor and its driven machinery and must at least be within sight of the motor and its driven machinery, unless one of the following conditions is complied with:

1. The controller or its disconnecting means is capable of being locked in the open position.

2. A manually operable switch, which will prevent the starting of the motor, is placed within sight of the motor location. This switch may be placed in the remote-control circuit of a remote-control type of switch.

3. Special permission is given by the authority enforcing the Code.

4. As otherwise specified in the rules governing hazardous locations.

The control point should be located so that it will be in the most accessible location for the operator of the machine driven by the motor. In the case of manual controllers the location of the control point will be the same as the location of the controller. For magnetic controllers the location of the control point will be the point of location of the "start" and "stop" push buttons which may or may not be the same as the location of the controller.

436. Overload Protection of Continuous-duty Motors.—Each continuous-duty motor must be protected against excessive overloads under running conditions by some approved protective device. This protective device, except for motors rated at more than 600 volts, may consist of thermal cutouts, thermal relays, thermal release devices, or magnetic relays in connection with the motor controller, fuses, or time-limit circuit breakers.

The National Electrical Code requires that the protection be as follows:

1. More than 1 Hp.—For a motor rated more than 1 hp., this protection shall be secured by the use of one of the following means:

a. A separate overcurrent device that is responsive to motor current. This device shall be rated or set at not more than 125 per cent of the motor full-load current rating for any type of motor marked to have a temperature rise not over 40°C., and at not more than 115 per cent for all other types of motors. If a motor installation includes a capacitor connected

on the load side of the motor overcurrent device, the full-load motor current must be reduced by the percentage given in Table 28 of Div. 11 before the rating of the motor overcurrent protective device is determined.

b. A protective device integral with the motor which is responsive to motor current or to both motor current and temperature. This device must be approved for use with the motor it protects on the basis that it will interrupt current to the motor when the motor is operated in an ambient temperature not more than 40°C. and with overcurrent of the percentage values given in paragraph *a* of this section. If the motor-current interrupting device is separate from the motor and its control circuit is operated by a protective device integral with the motor, it must be so arranged that the opening of the control circuit will result in interruption of current to the motor.

2. 1 Hp. or Less, Manually Started.—Any motor of 1 hp. or less that is manually started and is within sight from the starter location shall be considered as protected against overcurrent by the overcurrent device protecting the conductors of the branch circuit. This branch-circuit overcurrent device shall not be larger than that specified in Sec. **34** of Div. 11, except that any such motor may be used at 125 volts or less on a branch circuit protected at 20 amp. Any such motor which is out of sight from the starter location shall be protected as specified in subparagraph 3 for automatically started motors.

3. 1 Hp. or Less, Automatically Started.—Any motor of 1 hp. or less that is started automatically shall be protected against overcurrent by the use of one of the following means:

a. A separate overcurrent device that is responsive to motor current and rated or set in accordance with the rules given in Sec. **436,** part 1*a* for motors of more than 1 hp.

b. A protective device integral with the motor which is responsive to motor current or to both motor current and temperature. This device must be approved for use with the motor it protects on the basis that it will prevent dangerous overheating of the motor due to overload or failure to start. If the motor-current interrupting device is separate from the motor and its control circuit is operated by a protective device integral with the motor, it must be so arranged that the opening of the control circuit will result in interruption of current to the motor.

c. If part of an approved assembly does not normally subject the motor to overloads and is also equipped with other safety controls (such as safety combustion controls of a home oil burner) that protect the motor against damage due to stalled rotor current, no additional protection is required. Where such protective equipment is used, it shall be indicated on the name plate of the assembly where it will be visible after installation.

d. If the impedance of the motor windings is sufficient to prevent overheating due to failure to start, the motor may be protected as specified in subparagraph 2 for manually started motors.

Many a-c motors of less than $\frac{1}{20}$ hp., such as clock motors, series motors, and also some larger motors such as torque motors, come within this classification. It does not include split-phase motors having automatic switches to disconnect the starting winding.

4. Wound-rotor Secondaries.—The secondary circuits of wound-rotor a-c motors, including conductors, controllers, resistors, etc., shall be considered as protected against overcurrent by the motor-running overcurrent device.

5. Selection or Setting of Protective Device. Where the values specified for motor-running overcurrent protection do not correspond to the standard sizes or ratings of fuses, nonadjustable circuit breakers, thermal cutouts, thermal relays, the heating elements of thermal trip motor switches, or possible settings of adjustable circuit breakers adequate to carry the load, the next higher size, rating, or setting may be used, but not exceeding 140 per cent of the motor full-load current rating for motors rated on 40°C. rise basis and not exceeding 130 per cent for all other motors. If not shunted during the starting period of the motor, the protective device shall have sufficient time delay to permit the motor to start and accelerate its load.

6. Shunting during Starting Period.—If the motor is manually started, (including starting with a magnetic starter having push-button control), the running overcurrent protection may be shunted or cut out of circuit during the starting period of the motor, provided that the device by which the overcurrent protection is shunted or cut out cannot be left in the starting position; and the motor shall be considered as protected against overcurrent during the starting period, if fuses or time-delay circuit breakers rated or set at not over 400 per cent of the full-load current of the motor are so located in the circuit as to be operative during the starting period of the motor. The motor-running overcurrent protection shall not be shunted or cut out during the starting period, if the motor is automatically started.

7. Fuses, in Which Conductor.—If fuses are used for motor-running protection, a fuse shall be inserted in each ungrounded conductor, except that a fuse shall also be inserted in a grounded conductor for circuits supplied by wye-delta or delta-wye connected transformers when required by the authority enforcing the Code.

8. Number of Conductors Disconnected by Overcurrent Devices.—Motor-running protective devices, other than fuses or thermal cutouts, shall simultaneously disconnect a sufficient number of ungrounded conductors to interrupt current flow to the motor. The Code recommends that all ungrounded conductors be opened, if devices capable of accomplishing this are available.

9. Rating of Protective Device.—Motor-running overcurrent devices other than fuses shall have a rating of at least 115 per cent of the full-load current rating of the motor.

10. Automatic Restarting.—A motor-running protective device that can restart a motor automatically after overcurrent tripping shall not be installed unless approved for use with the motor it protects. A motor that can restart automatically after shutdown shall not be installed so that its automatic restarting can result in injury to persons.

If regular fuses are used for the overload protection of a motor, the fuses will have to be shunted during the starting period, since a regular fuse having a rating of 125 per cent of the motor full-load current would be blown by the starting current. Many cases of d-c motor and some wound-rotor-induction-motor installations will be an exception to this rule. Except for these exceptions it is not common practice to use regular fuses for the overload protection of motors. Time-lag fuses may be satisfactorily employed for the overload protection of motors, since ones rated at 125 per cent of the motor full-load current will not be blown by the starting current for ordinary conditions of motor service. In fact the manufacturers of these fuses recommend that, for ordinary service, fuses of a smaller rating than 125 per cent of the motor full-load current be employed. These recommendations are given in Sec. **437.** Typical heavy service conditions for use of the table are:

1. Motors slightly overloaded.
2. Motors with severe starting conditions, such as large fans, compressors, etc.
3. Motors which are started frequently or reversed quickly.
4. Motors which have the protective time-lag fuses located in places where high ambient temperatures prevail.

For extremely severe conditions the values of the last column should be used. They will meet the Code requirements for motor protection. For fractional-horsepower motors, time-lag fuses mounted directly on the motor, as discussed in Div. 4, will often be found advantageous.

If time-lag fuses of a rating not exceeding that of the last column of Sec. **437** are employed for the protection of a motor branch circuit, no additional motor overload protection will be required, the one set of fuses satisfying the requirements for both branch-circuit and motor overload protection.

Direct-current motors under ordinary conditions of service will not require a starting current of such value that it would blow regular fuses rated at 125 per cent of the motor full-load current. Standard manual starters for d-c motors are equipped with a starting resistance of a value which will limit the starting current on the first step to 150 per cent of the motor full-load current. This current for the normal duration of the starting period would not blow a fuse rated at 125 per cent of the full-load current. For ordinary conditions of service, therefore, it is common practice to employ regular fuses for the protection of d-c motors. In many cases what has been said for d-c motors will hold true for wound-rotor induction motors.

437. Recommendations for Size of Time-lag Fuses for Motor Overload Protection

(Bussmann Manufacturing Co.)

Amp. of motor or device	Usual hp. of motors											Amp. of fusetron		
	Single phase		Three phase				Two phase		Direct current			Ordinary service	Heavy service	Max.
	110 v.	220 v.	208 v.	220 v.	440 v.	550 v.	220 v.	440 v.	115 v.	230 v.	550 v.			
1.01– 1.05	...	...	.....	.....	.....	½	.....	.....	...	.....	.....	1.	1.25	1.6
1.06– 1.12	...	...	.....	.....	.....	¾	.....	½	⅛	.....	.....	1 25	1 25	1.6
1.13– 1.28	...	...	.....	.....	.....	.....	.....	¾	...	.....	.....	1.25	1.6	1.6
1.29– 1.40	...	...	.....	.....	½	1	.....	1	...	.....	¾	1.6	1.6	2
1.41– 1.60	...	...	.....	.....	¾	.....	.....	.....	...	.....	.....	1.6	2	2
1.61– 1.68	...	...	.....	.....	.....	.....	.....	.....	...	.....	.....	1.6	2	2.5
1.69– 1.80	...	⅛	.....	.....	1	.....	.....	.....	...	.....	1	2	2	2.5
1.81– 2.00	...	...	.....	.....	.....	1½	.....	1½	...	.....	.....	2	2.5	2.5
2.01– 2.10	...	...	.....	.....	.....	.....	.....	.....	...	.....	.....	2	2.5	3.2
2.11– 2.25	...	¼	.....	.....	.....	.....	½	.....	...	.....	.....	2.5	2.5	3.2
2.26– 2.56	⅛	⅛	.....	½	1½	2	¾	.....	¼	½	.....	2.5	3.2	3.2
2.57– 2.88	...	...	½	¾	.....	.....	.....	.....	...	.....	1½	3.2	3.2	4
2.89– 3.20	⅛	...	¾	.....	2	.....	1	2	⅓	.....	.....	3.2	4	4
3.21– 3.35	⅛	...	.....	1	.....	.....	.....	.....	...	¾	.....	3.2	4	5
3.36– 3.6	...	½	1	.....	.....	.....	.....	.....	...	.....	2	4	4	5
3.61– 4.0	...	...	.....	.....	.....	3	1½	3	...	.....	.....	4	5	5
4.01– 4.2	...	...	.....	.....	.....	.....	.....	.....	...	1	.....	4	5	6.25
4.21– 4.5	¼	...	.....	.....	3	.....	.....	.....	½	.....	.....	5	5	6.25
4.51– 5.0	¼	¾	1½	1½	.....	.....	2	.....	...	.....	3	5	6.25	6.25
5.01– 5.2	⅓	...	.....	.....	.....	.....	.....	.....	...	.....	.....	5	6.25	8
5.21– 5.6	⅓	1	.....	.....	.....	.....	.....	.....	...	.....	.....	6.25	6.25	8
5.61– 6.4	...	...	2	2	.....	5	.....	.....	...	1½	.....	6.25	8	8
6.41– 7.2	½	...	.....	.....	.....	.....	.....	5	¾	.....	.....	8	8	10
7.21– 8.0	½	1½	.....	.....	5	.....	3	.....	...	.....	.....	8	10	10
8.01– 8.4	...	1½	.....	.....	.....	.....	.....	.....	1	2	5	8	10	12
8.41– 9.0	¾	...	.....	3	.....	.....	.....	7½	...	.....	.....	10	10	12
9.01– 9.6	¾	2	3	.....	.....	7½	.....	.....	...	.....	.....	10	12	12
9.61– 10.5	...	2	.....	.....	.....	.....	.....	.....	...	.....	.....	10	12	15
10.6 – 12.0	1	2	.....	.....	7½	10	.....	10	...	.....	7½	12	15	15
12.1 – 12.6	1	...	.....	.....	.....	.....	.....	.....	...	3	.....	12	15	20
12.7 – 13.5	...	...	.....	.....	.....	.....	5	.....	...	.....	.....	15	15	20
13.6 – 15.7	...	3	.....	5	10	.....	.....	.....	...	.....	.....	15	20	20
15.7 – 16.0	1½	...	5	.....	.....	15	.....	15	...	.....	10	20	20	20
16.1 – 18.0	...	...	.....	.....	.....	.....	.....	.....	...	.....	.....	20	20	25
18.1 – 20.0	2	...	.....	.....	15	.....	7½	.....	...	5	.....	20	25	25
20.1 – 21.0	...	...	.....	.....	.....	20	.....	.....	...	.....	.....	20	25	30
21.1 – 22.5	...	...	.....	7½	.....	.....	.....	.....	...	.....	.....	25	25	30
22.6 – 24.0	...	5	7½	.....	.....	.....	10	20	...	.....	15	25	30	30
24.1 – 26.1	...	...	.....	.....	20	25	.....	.....	...	.....	.....	25	30	35
26.2 – 27.3	...	...	.....	10	.....	.....	.....	.....	...	.....	.....	30	30	35
27.4 – 28	...	...	.....	.....	.....	.....	.....	25	...	.....	.....	30	35	35
28.1 – 31.3	...	...	10	.....	.....	.....	.....	.....	...	7½	20	30	35	40
31.4 – 32	...	...	.....	.....	25	30	.....	.....	...	.....	.....	35	35	40
32.1 – 36	...	...	.....	.....	.....	.....	15	30	...	.....	.....	35	40	45
36.1 – 36.6	...	...	.....	.....	.....	.....	.....	.....	...	.....	.....	35	40	50

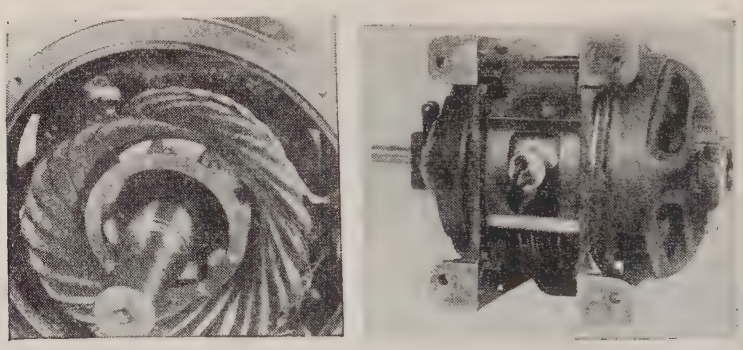
Recommendations for Size of Time-lag Fuses for Motor Overload Protection (*Continued*)

Amp. of motor or device	Usual hp. of motors.								Amp. of fusetron		
	Three phase				Two phase		Direct current		Ordinary service	Heavy service	Max.
	208 v.	220 v.	440 v.	550 v.	220 v.	440 v.	230 v.	550 v.			
36.7 – 40	15	15	30	40	....	....	10	25	40	45	50
40.1 – 42	....	....	....	....	....	....	....	....	40	50	60
42.1 – 45	....	....	....	....	20	40	....	30	45	50	60
45.1 – 47	....	....	....	....	....	....	....	....	45	60	60
47.1 – 48	....	....	....	....	....	....	....	....	50	60	60
48.1 – 52	....	20	40	50	....	....	....	....	50	60	70
52.1 – 56	20	....	....	....	25	50	15	....	60	60	70
56.1 – 62	....	....	50	60	....	....	....	40	60	70	80
62.1 – 64	....	....	....	....	....	....	....	....	70	70	80
64.1 – 72	25	25	....	75	30	60	....	....	70	80	90
72.1 – 80	....	30	60	....	....	75	20	50	80	90	100
80.1 – 84	30	....	....	....	....	....	....	....	80	100	110
84.1 – 88	....	....	....	....	40	....	....	....	90	110	110
88.1 – 90	....	....	75	....	....	....	....	60	90	100	125
90.1 – 94	....	....	....	....	....	....	25	....	90	110	125
94.1 –100	....	....	....	100	....	.....	....	....	100	110	125
100.1 –104	....	40	....	....	....	.....	....	....	100	125	150
104.1 –113	40	....	....	....	50	100	30	75	110	125	150
113.1 –120	....	....	....	....	....	.....	....	....	125	150	150
120.1 –130	....	50	100	125	60	.....	....	....	125	150	175
130.1 –135	50	....	....	....	....	125	....	....	150	150	175
135.1 –140	....	....	....	....	....	....	....	....	150	175	175
141 –156	....	60	125	150	75	150	40	100	150	175	200
157 –160	60	....	....	....	....	....	....	....	175	200	200
161 –180	....	75	150	....	....	....	50	....	175	200	225
181 –200	75	....	....	200	....	....	....	125	200	225	250
201 –208	....	....	....	....	....	200	....	....	200	250	300
209 –227	....	....	....	....	100	....	60	150	225	250	300
228 –234	....	....	....	....	....	....	....	....	225	300	300
235 –240	....	....	200	....	....	....	....	....	250	300	300
241 –260	100	100	....	....	....	....	....	....	250	300	350
261 –280	....	....	....	....	125	....	75	200	300	300	350
281 –312	....	....	....	....	....	....	....	....	300	350	400
313 –320	....	125	....	....	150	....	....	....	350	400	400
321 –360	125	150	....	....	....	....	100	....	350	400	450
361 –400	150	....	....	....	....	....	....	....	400	450	500
401 –450	....	....	....	....	200	....	125	....	450	500	600
451 –480	....	....	....	....	....	....	....	....	500	600	600

Figures given above are only approximate. See name-plate rating on motor. Horsepower of motor gives no definite indication of size of time-lag fuse to be used, as amperage of a-c motors of the same size varies a great deal.

438. Thermoguard motors (Westinghouse Electric & Manufacturing Co.) are equipped with a Built-in Watchman which is mounted directly in the motor. The Watchman consists of a thermostat which when heated above a certain temperature opens two small contacts within the

enclosing case of the thermostat. The thermostat is mounted on the windings or stator iron of a motor. The contacts are provided with leads so that they may be connected in a control circuit in a manner that



I. II.

FIG. 163.—Methods of mounting thermostats for thermoguard motors. (I) Thermostat mounted on winding. (II) Thermostat mounted in base of motor frame. (*Westinghouse Electric & Manufacturing Co.*)

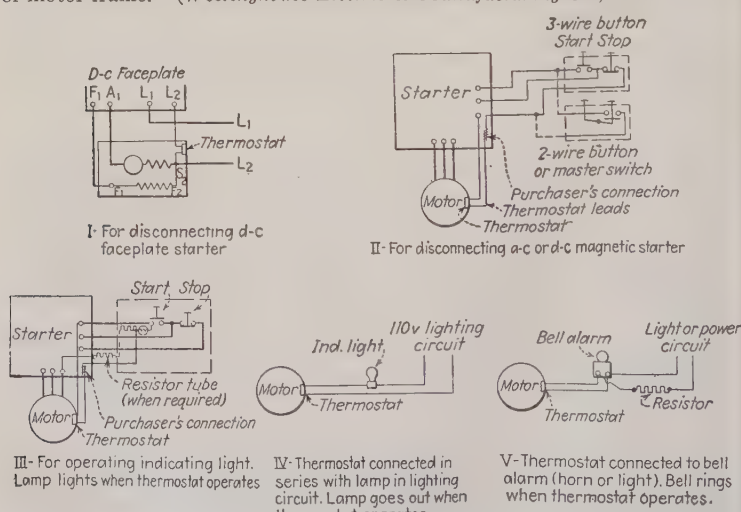


FIG. 164.—Connections for thermostats of thermoguard motors. (*Westinghouse Electric & Manufacturing Co.*)

will cause the controller to disconnect the motor or give a warning signal when the thermostat operates because of overheating of the motor (Fig. 164). The manner of mounting the thermostat is shown in Fig. 163. Thermoguard motors must be equipped with an additional over-

load protective device in the normal manner. The thermoguard device does give additional protection against overheating of the motor due to the following causes:

1. Too frequent starting.
2. Frequently repeated overloads.
3. High room temperatures.
4. Abnormal voltage.
5. Ventilation failure.

439. Overload Protection of Short-time-duty Motors.—The National Electrical Code does not require any motor overload protective device for motors in classes of service having short-time, intermittent, periodic, or varying duty. According to their rules, motors in these classes of service are considered as sufficiently protected by the branch-circuit overload protective device, provided that the branch-circuit protection does not exceed the percentage of full-load current given in Tables 13 and 14, of Div. 11. It is best practice, however, to protect the motor with a thermal or inverse-time–limit magnetic overload device.

440. Motor Switches.—Each motor with its controller must be provided with some form of approved manual disconnecting means, as at S_M in Figs. 161 and 162. This disconnecting means, when in the open position, must disconnect both the controller and the motor from all ungrounded supply wires. It must be of a type which will plainly indicate whether it is in the open or closed position. For motors rated at not more than 600 volts it may consist of a manually operated air-break switch, manually operated circuit breaker, or a manually operated oil switch. An oil switch used for this purpose must not, except with special permission, have a rating greater than 100 amp. The oil switch or circuit breaker may be equipped for electrical operation in addition to the hand mechanism. For motors rated at more than 600 volts, the equipment required for the branch-circuit protection will constitute the disconnecting means.

No additional switch is required with most types of manual across-the-line starters, since their switch acts as the disconnecting means. All magnetic types of starters and controllers must be provided with a switch ahead of the starter. All autotransformer starters require a separate disconnecting switch ahead of the starter.

If a time-limit manual circuit breaker is employed for the overload protection of the motor, it will serve as the disconnecting switch, provided that it opens all ungrounded wires of the circuit. If fuses are used for the overload protection of the motor and the starting current of the motor is greater than 125 per cent of motor full-load current, a double-throw or a two-position switch will be required in order to short-circuit the running fuses during the starting period as at II in Figs. 161 and 162. This switch must be of such a type that it cannot be left in the starting position.

The motor switch must be a motor-circuit switch, rated in horsepower, or a circuit breaker except under the following conditions:

1. For stationary motors of ⅛ hp. or less the branch-circuit overload device may serve as the disconnecting means.

2. For stationary motors of 2 hp. or less operating at not more than 300 volts, a general-use switch having an ampere rating at least twice the full-load–motor-current rating may be used.

3. A general-use switch may be used for motors of a size over 2 hp. but not larger than 50 hp. which are equipped with a compensator starter, provided that all of the following provisions are complied with:

a. The motor drives a generator provided with overcurrent protection.

b. The compensator is capable of interrupting the stalled-rotor current, is provided with a no-voltage release and with overload protection not exceeding 125 per cent of the motor full-load current rating.

c. Separate fuses or a circuit breaker, rated or set at not more than 150 per cent of the motor rated current, are provided in the branch circuit.

4. When the motor rating is more than 50 hp., and the switch is not to be used for shutting down the motor, the motor switch may be a general-use switch or an isolating switch. (In this case, the switch should be plainly marked "Do not open under load.")

5. For portable motors an attachment plug and receptacle may serve as the disconnecting means.

A **motor-circuit switch** is intended for use in a motor branch circuit and is rated in horsepower. It must be capable of interrupting the maximum operating overload current of a motor of the same horsepower as the switch at the rated voltage. It must have a continuous rating of at least 115 per cent of the full-load current of the motor. If a fused switch is used, it must be large enough to accommodate the size of fuses employed.

If the motor switch is used for shutting down the motor, it should be located as close as possible to the motor and its driven machinery, and in the most accessible location for the operator. If the motor switch is not used for shutting down the motor but simply as a disconnecting means, it may be located at any convenient readily accessible point, provided it either is within sight of the motor or may be locked in the open position. Under these conditions one switch may be employed to serve the double purpose of motor- and branch-circuit switch as shown at S_M in III of Fig. 161. If an installation consists of a single motor, the service switch may serve as the disconnecting means it meets all the above conditions.

441. Group Switching.—Under the following conditions the National Electrical Code rules will allow a single switch to be provided for a group of motors if the motors are rated at not more than 600 volts:

1. The switch has a rating not less than that required for a single motor of a rating equal to the sum of the horsepowers or currents of all the motors of the group.

2. Motors that drive the several parts of a single machine or apparatus, such as cranes, hoists, and metal and woodworking machines.

3. Groups of small motors under the protection of one set of automatic overload protective devices, as permitted by the Code rules (see Sec. **436**).

4. Groups of motors in a single room within sight of the disconnecting means.

442. Branch-circuit Protection.—The wires of motor branch circuits must be protected against overload by means of some protective device located at the point where the branch-circuit wires are connected to the feeder or main, as at location P_2 in Figs. 161 and 162. The National Electrical Code rules, however, allow the size of these branch-circuit overload protective devices to be considerably greater than the allowable carrying capacity of the wires. This is for the purpose of allowing the passage of the starting current without the employment of excessively large conductors.

With this practice, the motor overload protective device will protect against overloads of moderate severity, and the branch-circuit protective device will protect against short circuits. The recommended maximum rating of fuses and setting of circuit breakers for motor branch circuits supplying an **individual motor** are given in Tables 12 to 14 of Div. 11.

The National Electrical Manufacturer's Association (N.E.M.A.) has adopted a standard of identifying code letters that may be marked by the manufacturers on motor name plates to indicate the motor kilovolt-ampere input with locked rotor. These code letters with their classification are given in Table 12 of Div. 11. At the time of this writing the code letters have not been classified with respect to the types of motors to which each will normally apply. In determining the starting current to employ for circuit calculations, use values from Table 13 of Div. 11 if the motor name plate is marked with the N.E.M.A. identifying code letter; otherwise, use values from Table 14 of Div. 11.

Although the branch-circuit overload protective device must pass the starting current of the motor, it is not necessary that the rating of the overload protective device be as great as the maximum value of the starting current of the motor. Owing to the time-lag characteristics of fuses or time-limit circuit breakers, the starting current, which lasts for only a short time, will not rupture fuses or operate time-limit circuit breakers of a considerably smaller rating than the maximum value of the starting current. The percentage of the maximum starting current that fuses must be rated for, or time-limit circuit breakers set for, in order that the starting current will not open the circuit, depends upon the frequency and duration of the starting periods. Under ordinary starting conditions, fuses rated, or time-limit circuit breakers set at, from 50 to 67 per cent of the maximum starting current will allow the passage of the starting current. Branch motor circuits protected according to the percentages of the full-load currents given in Tables 12, 13, and 14 of Div. 11 will allow the passage of the starting current for ordinary starting service.

When it is found that the maximum rating or setting of the motor branch-circuit protective device recommended in these tables is not large enough to allow the motor to start, the authority enforcing the Code may permit a sufficient increase in the rating or setting of the protective device to allow the motor to start. In no case shall the rating or setting of the protective device exceed 400 per cent of the full-load current of the motor.

Either fuses or circuit breakers may be employed for the protection of motor branch circuits for motors rated at not more than 600 volts.

When circuit breakers are used on a-c motor branch circuits, they must be of the time-limit type. On d-c motor branch circuits, circuit breakers may be of either the instantaneous or the time-limit type.

It is often not convenient or practicable to locate the branch-circuit overload protective device directly at the point where the branch-circuit wires are connected to the main. In such cases the size of the branch-circuit wires between the mains and the branch-circuit protective device must be the same size as the mains, unless the length of these wires is not greater than 25 ft. When the length of the branch-circuit wires between the main and the branch-circuit protective device is not greater than 25 ft., the Code rules allow the size of these wires to be such that they have a carrying capacity of only one-third of the carrying capacity of the mains (see Fig. 161) if they are protected against mechanical injury.

If the motor overload protective device consists of thermal cutouts or thermal relays, the main must be protected by fuses rated at, or circuit breakers set for, not more than four times the full-load current of the smallest motor fed from the circuit unless the motor overload protective device is approved for group fusing. If the motor overload protective device is approved for group fusing, the overload protection of the main must not exceed the maximum allowable value as stamped on the motor overload protective device. Some motor overload protective devices are approved for use with main or feeder fuses as large as 100 amp.

If the motor overcurrent running protection is shorted out during the starting period, the branch-circuit protection must be rated or set at not over 400 per cent of the full-load current of the motor.

Each motor branch circuit and feeder of more than 600 volts shall be protected against overcurrent by one of the following means:

1. A circuit breaker of suitable rating so arranged that it can be serviced without hazard.

2. Fuses of the oil-filled or other suitable type. Fuses shall be used with suitable disconnecting means, or they shall be of a type that can also serve as the disconnecting means. They shall be so arranged that they cannot be re-fused or replaced while they are energized. The voltage and current ratings of fuses shall be limited to the values permitted by the code.

For branch motor circuits supplying several motors and no other equipment except that directly associated with the motors, the branch-

circuit protection may be in accordance with the following statements: For such circuits, where individual motors are not required to have motor overload protective devices, the branch-circuit protection must be rated at not more than 20 amp. for 125-volt circuits and at not more than 15 amp. for circuits having a voltage from 126 to 600 volts. For circuits where the individual motors are provided with motor overload protective devices, the branch-circuit protection may have a rating as allowed for the protection of motor feeders. Refer to Sec. **447** for the method of computing rating. If the motor overload protective devices are shorted out during the starting period or if the motor overload protective devices are thermal cutouts or relays, the same conditions must be fulfilled as previously stated for a branch supplying a single motor.

443. Branch-circuit Switches.—The National Electrical Code rules do not require a switch to be located on the line side of the overload protective device, as at S_B in Fig. 161, unless there is no switch located as at S_M in Fig. 161, I. When there is no switch located at S_M a switch must be located at S_B in order to serve as a motor switch (see Sec. **440**). If a circuit breaker is employed for the branch-circuit overload protection it will serve as both a switch and an overload protective device. Although not required, a branch-circuit switch is very convenient. It provides a means of disconnecting the entire branch circuit from the supply. When such a switch is not provided, the fuses must be removed from the circuit when the circuit is live. For this reason it is recommended that a branch-circuit switch be provided on all circuits operating at a voltage greater than 220 volts unless a safety-fuse type of panel is used (see Sec. **97,** Div. 4). The branch-circuit switch must have fuse clips large enough to accommodate the branch-circuit fuses, as required by Sec. **442,** and Tables 13 and 14 of Div. 11.

If a branch-circuit switch is located within sight from the motor controller location, it must comply with the requirements for a motor switch. Refer to Sec. **440.**

444. Size of Wire for Motor Branch Circuits.—The wires of a branch circuit supplying a single continuous-duty motor must have a carrying capacity of at least 125 per cent of the full-load rated current of the motor. The size of the wires of a motor branch circuit supplying a single motor in short-time duty service may be different from those for a continuous-duty motor. In most cases the carrying capacity of the wires need not be greater than the percentages of the full-load current of the motor given in Table 10 of Div. 11.

The wires between the slip rings and the controller of a wound-rotor induction motor must have a carrying capacity of at least 125 per cent of the full-load secondary current of the motor for continuous-duty motors. For other than continuous-duty motors the carrying capacity of the wires must be not less than the percentages of full-load secondary

currents as given in Table 10 of Div. 11. The wires between the secondary controller and the resistance of a wound-rotor induction motor must have a carrying capacity which is not less than the percentages of the full-load secondary current of the motor given in Table 10*A* of Div. 11.

The wires of a branch circuit supplying several motors but no other equipment except that directly associated with the motors must have a current-carrying capacity of not less than 125 per cent of the full-load current rating of the largest motor plus the sum of the full-load current ratings of the remainder of the motors.

For the size of the tap conductors, refer to Secs. **433** and **434.**

If the length of the tap between the feeder or main and the branch-circuit protective devices is not over 5 ft. long and is protected against mechanical injury by conduit, electrical metallic tubing, or metal gutters, the tap from the feeder or main to the protective devices may be of the same size as the branch-circuit conductors.

445. Remote-control Circuits.—Control or operating circuits for magnetic controllers or switches should be connected to the load side of the motor-disconnecting switch so that there is a means of disconnecting them from all source of supply, unless a separate switch is used for the control circuit. If a transformer or other device is used to obtain a reduced voltage for control circuits, the device should be connected to the load side of the motor-disconnecting means.

The conductors of these control circuits will be considered as properly protected by the motor branch-circuit overcurrent protective devices under any one of the following conditions:

1. If the rating or setting of the branch-circuit overcurrent device is not more than 500 per cent of the carrying capacity of the control-circuit conductors.

2. If the controlled device and the point of control (start and stop buttons, pressure switch, thermostatic switch, etc.) are both located on the same machine and the control circuit does not extend beyond the machine.

3. If the opening of the control circuit would create a hazard; as, for example, the control circuit of pump motors, etc.

If any one of the above conditions is not fulfilled, then the conductors of the control circuits should be protected by a protective device that is not of the so-called time-lag type and that is rated or set at not more than 500 per cent of the carrying capacity.

446. Size of Motor Feeders or Mains.—For the determination of the size of motor mains or feeders, refer to Div. 3.

447. Overload Protection of Motor Feeders or Mains.—The size of the protective equipment for motor feeders or mains is determined from the so-called starting current of the circuit, as explained in Sec. **60** of Div. 3.

Fuses or circuit breakers may be used for the overload protection of motor feeders or mains.

If thermal cutouts, thermal relays, or other devices that are not capable of opening short circuits are used for the motor overcurrent device of motors supplied by individual branch circuits, then the rating or setting of the feeder protective device must be not over four times the rating of the smallest motor so protected, unless the motor protective device is approved for group installation. If the motor overload protective device is approved for group installation, the rating or setting of the feeder protective device must not exceed the maximum allowable rating marked on the motor protective device of the smallest motor so protected.

If the motor overload protective devices are cut out during the starting period for motors supplied by individual branch circuits, then the rating or setting of the feeder protective device must be not more than 400 per cent of the full-load current of the smallest motor so protected.

448. Motor-wiring tables are given in Tables 34 to 36 of Div. 11. These tables give data on the size of the component parts of motor branch circuits in accordance with the 1947 edition of the National Electrical Code. Refer to Sec. **431.** If the wiring is to be done in a locality which has adopted local motor-wiring tables of its own, the tables of that particular district should be adhered to instead of the values given here. The values for the sizes of wires given in the tables are the minimum sizes allowed by the Code. They do not take into account voltage drop in the circuit. For long circuits the voltage drop should be computed in order to determine whether the size of wire should be increased so as to keep the voltage drop within an allowable amount (see Div. 3).

DIVISION 8

OUTSIDE DISTRIBUTION

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POLE LINES—GENERAL, CONSTRUCTION, AND EQUIPMENT

1. The reports of the committee on overhead line construction of the National Electric Light Association contain what are probably the best and most complete specifications for pole-line construction for lighting and power distribution that have ever been compiled. Some of the matter in this section regarding pole lines has been abstracted from those reports. The National Electric Light Association has been reorganized and succeeded by the Edison Electric Institute (E.E.I.). As specifications and standards of the N.E.L.A. organization are revised, they will be known as those of the E.E.I.

2. The National Electrical Safety Code, *U. S. Bureau of Standards Handbook*, series 3, comprises an exhaustive collection of rules for proper installation, maintenance, and operation of electrical distribution systems. Companies are now, in general, endeavoring to follow these rules. Ultimately, it is believed, their adoption will be universal.

3. There are three principal types of overhead line construction:

1. Bare or weatherproof covered wire supported by insulators mounted on or hung from crossarms located on buildings or near the tops of poles.
2. Weatherproof covered wire supported by insulators mounted on racks on the side of buildings or poles.
3. Insulated aerial cable which is either self supporting from clamps bolted to sides of poles or crossarms or supported by messenger cable from clamps bolted to the sides of poles or crossarms. (See Div. 2 for descriptions of the types of wire and cable.)

4. There are four main types of poles used for overhead line construction:

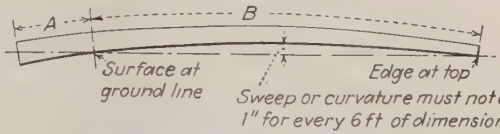
1. Wood poles.
2. Steel poles.
3. Reinforced-concrete poles.
4. Structural-steel fabricated towers.

5. The most common woods for poles are:

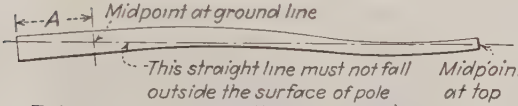
1. Western red cedar, found in the Rocky Mountain regions from southern Alaska to the central part of California.
2. Northern white cedar, found in Michigan, Wisconsin, Minnesota, and elsewhere throughout northeastern United States and southeastern Canada.
3. Southern yellow pine, found in Virginia, North and South Carolina, Tennessee, and south into Florida and west to Texas.

4. Chestnut, found in Virginia, West Virginia, and in some of the other southern states, virtually all blight-killed but in a good state of preservation.

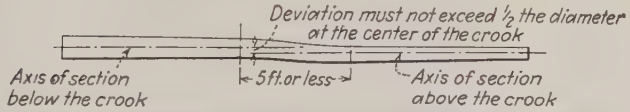
5. Redwood, found on the Pacific Coast.



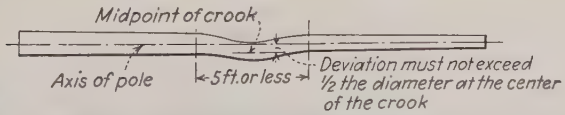
I-SWEEP IN ONE PLANE AND ONE DIRECTION



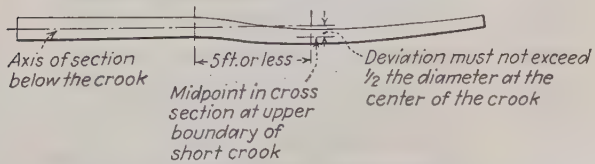
II-SWEEP IN TWO PLANES (DOUBLE SWEEP) OR IN TWO DIRECTIONS IN ONE PLANE (REVERSE SWEEP)
(Applies to western red cedar and southern pine poles only)
For northern white cedar and chestnut poles the sweep in each plane must not exceed the value in I



III-SHORT CROOK WHERE THE REFERENCE AXES ARE APPROXIMATELY PARALLEL



IV-SHORT CROOK WHERE AXES OF SECTIONS ABOVE AND BELOW THE CROOK COINCIDE OR ARE PRACTICALLY COINCIDENT



V-SHORT CROOK WHERE AXIS OF SECTION ABOVE SHORT CROOK IS NOT PARALLEL OR COINCIDENT WITH AXIS BELOW THE CROOK

FIG. 1.—Allowable sweeps and crooks in wood poles. (*American Standards Association.*)

Of these, the yellow pine is most commonly used in the eastern states, red or white cedar in the central states, and redwood on the West Coast. According to the "Standard Handbook," about two-thirds of all poles used are cedar.

6. Wood poles are classified into ten classes according to the circumference at the top of the pole and the circumference at a point 6 ft. from the butt, as given in the following table:

Class	1	2	3	4	5	6	7	8	9	10
Min. top circumference, in.	27	25	23	21	19	17	15	18	15	12
Length of pole, ft.	Min. circumference 6 ft. from butt, in.									
Northern White Cedar Poles										
16	....	....	....	....	26.0	24.0	22.0	No butt requirement		
18	....	....	32.5	30.0	28.0	25.5	23.5			
20	39.5	37.0	34.0	31.5	29.0	27.0	25.0			
22	41.0	38.5	36.0	33.0	30.5	28.0	26.0			
25	43.5	41.0	38.0	35.5	32.5	30.0	28.0			
30	47.5	44.5	41.5	38.5	35.5	33.0	30.5			
35	50.5	47.5	44.0	41.0	38.0	35.0	32.5			
40	53.5	50.0	46.5	43.5	40.0	37.0				
45	56.0	52.5	49.0	45.5	42.0					
50	58.5	55.0	51.5	47.5	44.0					
55	61.0	57.5	53.5	49.5	46.0					
60	63.5	59.5	55.5	51.5						
Western Red Cedar Poles										
16	....	....	....	....	23.0	21.5	19.5	No butt requirement		
18	....	....	28.5	26.5	24.5	22.5	21.0			
20	34.5	32.0	30.0	28.0	25.5	23.5	22.0			
22	36.0	33.5	31.5	29.0	27.0	25.0	23.0			
25	38.0	35.5	33.0	30.5	28.5	26.0	24.5			
30	41.0	38.5	35.5	33.0	30.5	28.5	26.5			
35	43.5	41.0	38.0	35.5	32.5	30.5	28.0			
40	46.0	43.5	40.5	37.5	34.5	32.0				
45	48.5	45.5	42.5	39.5	36.5					
50	50.5	47.5	44.5	41.0	38.0					
55	52.5	49.5	46.0	42.5	39.5					
60	54.5	51.0	47.5	44.0						
65	56.0	52.5	49.0	45.5						
70	57.5	54.0	50.5	47.0						
75	59.5	55.5	52.0	48.5						
80	61.0	57.0	53.5	49.5						
85	62.5	58.5	54.5							
90	63.5	60.0	56.0							

Class	1	2	3	4	5	6	7	8	9	10
Min. top circumference, in	27	25	23	21	19	17	15	18	15	12
Length of pole, ft.	Min. circumference 6 ft. from butt, in.									

Creosoted Southern Pine Poles

16	....	....	....	....	21.5	19.5	18.0	No butt
18	....	....	26.5	24.5	22.5	21.0	19.0	requirement
20	31.5	29.5	27.5	25.5	23.5	22.0	20.0	
22	33.0	31.0	29.0	26.5	24.5	23.0	21.0	
25	34.5	32.5	30.0	28.0	26.0	24.0	22.0	
30	37.5	35.0	32.5	30.0	28.0	26.0	24.0	
35	40.0	37.5	35.0	32.0	30.0	27.5	25.5	
40	42.0	39.5	37.0	34.0	31.5	29.0	27.0	
45	44.0	41.5	38.5	36.0	33.0	30.5	28.5	
50	46.0	43.0	40.0	37.5	34.5	32.0	29.5	
55	47.5	44.5	41.5	39.0	36.0	33.5		
60	49.5	46.0	43.0	40.0	37.0	34.5		
65	51.0	47.5	44.5	41.5	38.5			
70	52.5	49.0	46.0	42.5	39.5			
75	54.0	50.5	47.0	44.0				
80	55.0	51.5	48.5	45.0				
85	56.5	53.0	49.5					
90	57.5	54.0	50.5					

Chestnut Poles

16	....	....	....	....	22½	21	19½	No butt
18	....	....	28	26	24	22	20½	requirement
20	33½	31½	29½	27	25	23	21½	
22	35	33	30½	28½	26½	24½	22½	
25	37	34½	32½	30	28	25½	24	
30	40	37½	35	32½	30	28	26	
35	42½	40	37½	34½	32	30	27½	
40	45	42½	39½	36½	34	31½	29½	
45	47½	44½	41½	38½	36	33	31	
50	49½	46½	43½	40	37½	34½	32	
55	51½	48½	45	42	39	36		
60	53½	50	46½	43½				
65	55	51½	48	45				
70	56½	53						

7. Approximate Weights of Wood Poles in Pounds

(The MacGilles and Gibbs Co.)

Length of pole, ft.	Northern white cedar										Western red cedar									
	Class										Class									
	1	2	3	4	5	6	7	8	9	10	1	2	3	4	5	6	7	8	9	10
16	.....	.....	.....	.....	230	190	135	135	105	85										
18	.....	.....	420	300	250	210	155	155	125	95										
20	720	600	440	350	300	230	190	190	130	100	700	600	500	400	300	225	200	180	135	100
22	820	780	540	500	400	315	200	225	170	120										
25	1,020	980	600	515	420	300	225	250	200	150	850	720	600	480	400	320	250	225	200	135
30	1,320	1,170	870	630	520	420	350	350	275	...	1,000	850	730	610	500	420	350	325	250	
35	1,620	1,320	1,060	820	720	510	450	...	...	...	1,200	1,000	850	750	650	560	470	450		
40	2,040	1,675	1,280	1,020	790	625	...	...	...	...	1,500	1,300	1,100	900	800	700				
45	2,640	1,970	1,535	1,215	1,080	...	...	...	...	...	1,800	1,550	1,300	1,150	1,000					
50	3,200	2,640	1,860	1,470	1,380	...	...	...	...	...	2,000	1,800	1,550	1,400	1,300					
55	3,800	2,960	2,260	1,620	1,560	...	...	...	...	...	2,300	2,000	1,750	1,600	1,600					
60	4,500	3,460	2,640	1,700	.....	...	...	...	...	...	2,600	2,200	2,000	1,900						
65	.....	.....	.....	.....	.....	...	...	...	...	...	3,200	2,500	2,300	2,200						
70	.....	.....	.....	.....	.....	...	...	...	...	...	3,600	3,000	2,700	2,600						
75	.....	.....	.....	.....	.....	...	...	...	...	...	4,200	3,600	3,100	3,000						
80	.....	.....	.....	.....	.....	...	...	...	...	...	5,000	4,200	3,600	3,500						
85	.....	.....	.....	.....	.....	...	...	...	...	...	5,500	4,500	4,000							
90	.....	.....	.....	.....	.....	...	...	...	...	...	6,600	5,600	4,800							

8. Wood-pole Specifications.—The American Standards Association (A.S.A.) has standardized the specifications and dimensions for wood poles. American Standards Association specifications provide that all poles shall be free from sap rot, cracks, bird holes, plugged holes, injurious checks, and damage by marine borers. All poles shall be free from splits, shakes, hollow, and decay in the tops. Nails, spikes, and other metal shall not be present unless specifically authorized by the purchaser. There are further detailed restrictions regarding blue sap stain, hollow centers, shakes in the butt surface, splits, grain twist, insect damage, scars, etc., which vary with the different types of poles. Anyone interested in such details is advised to consult the A.S.A.

Allowable deviations from straight poles are illustrated in Fig. 1. Dimension *A* should be taken from the following table:

A, ft.	3½	4	5	5½	6	6½	7	7½	8	8½	9	9½	10	10½	11
Total length of pole, ft..	16–18	20–22	25	30	35–40	45	50	55	60	65	70	75	80	85	90

9. Preservation of Poles.—Owing to the continually increasing scarcity of timber and the labor cost of replacing decayed poles, general practice is to impregnate poles with some substance which resists or retards decay. Southern pine poles generally are pressure-treated for their entire length. Common practice is to treat only the butt of poles of other woods, because, since these woods are naturally resistant to decay, practically all decay occurs within the portion 1½ ft. above or below the ground line.

10. Methods of Butt-treating. (Naugle Pole & Tie Co.)—The specifications for each of the three methods of treating require: Poles shall be seasoned at least four **seasoning months** before the treatment (see Sec. **11**). All fibrous inner bark and foreign substances must be thoroughly removed from that portion of the pole between the points 1½ ft. above and 1½ ft. below the ground line. In general, the methods of treatment are as follows: **Treatment A** provides for a continuous submersion in hot Carbolineum (a coal-tar derivative) for a minimum interval of 15 min. **Treatment AA** provides for a continuous submersion in hot Creosote for a minimum interval of 15 min. **Treatment B** provides for a continuous submersion in hot Creosote for a minimum interval of 4 hr., to be followed by a continuous submersion in cold Creosote for a minimum interval of 2 hr. In each of these three treat-

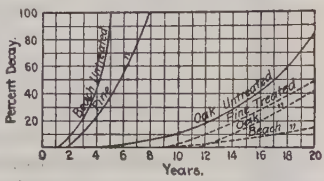


FIG. 2.—Life of treated and untreated poles.

ments the poles are placed in upright tanks with the butts continuously submerged to a height of 1½ ft. above the ground line.

Figure 2 shows, as would be expected, that the softer and more porous woods that suffer most rapid decay are most benefited, and have the longest life after treatment. Such woods can absorb the most oil. The cost of treatment varies with the amount of oil injected and with local conditions.

11. Calendar months are rated in equivalent seasoning months as follows:

Calendar month.	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
Seasoning month.	⅛	⅛	¼	½	¾	1	1	1	1	¾	⅜	⅛

Poles which have been properly piled for seasoning must be seasoned for a total of 4 seasoning months, counting the seasoning months as given in the above table. For example, poles which are cut in January or February must be seasoned to the end of August before the time will have equaled 4 "seasoning months."

FIG. 3.—Bates expanded steel pole.

12. Steel poles are made in three general types: (1) latticed, (2) expanded truss, and (3) tubular. The latticed type is made from structural-steel angles or channels joined and braced by latticed crossbars. The expanded truss is made from structural H sections, the web of which has been sheared by a rotary shear at fixed intervals so as to remove some of the metal. The pole is then heated to a cherry red and expanded by a special machine which grips the flanges and pulls them apart to the desired width (see Fig. 3). Latticed and expanded-truss steel poles are used for medium-voltage transmission lines with spans 250 to 350 ft. in length. Their life is 25 to 50 years or more, depending on the adequacy of painting and upkeep. Tubular poles are built up from lengths of steel tubing, using a large-diameter tube for the base and successively smaller ones for the upper sections. They have been extensively used for street-railway and trolley-bus wiring in cities, where appearance is important. Their higher cost has prevented their use through open country.

13. Fabricated steel towers are made from four main structural angles as uprights, cross braced with smaller structural angles. Steel towers are ordinarily used for high-voltage lines with spans over 350 ft.

14. The design of reinforced concrete poles requires considerable skill. Where one who is unfamiliar with concrete-pole design must build them, he had best accept the proportions of poles that have been built and are giving good service. A very useful booklet, "Concrete Poles," will be mailed free to any one interested by the Universal Portland Cement Co. of Pittsburgh. This book gives the dimensions of many concrete poles. The design of Fig. 4 is from the booklet. The pole is proportioned for a 150-ft. span to withstand a gale successfully, with the wind at a velocity of 70 miles per hour and ½ in. of ice on the wires. The horizontal load thus imposed by the wind on all the 18 wires, tending to overturn the pole, is 2,100 lb. The sides of the reinforcing bars are 1¼ in. in from the faces of the pole. The concrete is a 1:2:4 mixture. It should be mixed wet, using carefully selected materials with the fine aggregate next to the forms. Air bubbles should be eliminated by careful tamping or churning. Corners of the pole should be chamfered off. The square reinforcing rods, which are of the mechanical-bond type, are bound together by a web system not shown in the illustration. The web system consists of a spiral of No. 12 steel wire wound outside the rods and securely bound to them. The rods are also secured together with horizontal ties 1 in. wide and ¼ in. thick, spaced 3 to 5 ft. apart. The reinforcement thus forms an independent skeleton which can be assembled and lowered into the forms. It is stated that it is most economical to cast poles exceeding 35 ft. in height in their final vertical positions. Shorter poles are erected with a derrick. Gains for crossarms and holes for bolts are cast in poles. Metal pole steps may be cast in solid also.

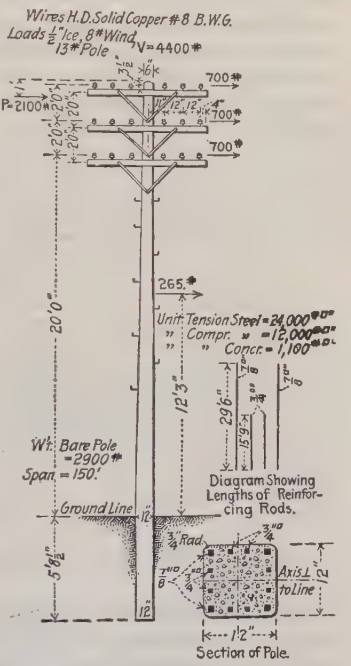


FIG. 4.—A 30-ft. reinforced-concrete pole. (*Universal Portland Cement Co.*)

15. Reinforced-concrete poles ("Standard Handbook") are the most permanent and usually the most expensive. The life of a properly designed concrete pole is practically unlimited. The facility with which special purposes may be served with reinforced concrete is also a great advantage. The exterior form may easily be modified to harmonize

with any desired scheme of decoration. When it is desired to lead wires from the pole top to ground, the poles may be made hollow, and thus at a slight additional cost the wires are completely hidden from view and protected from the weather. Concrete poles may fail, but they will not fall to the ground. The principal drawback to this form of construction has been the cost and the difficulty of manufacture. They are heavy and cumbersome to transport, so that, where possible, it is well to make them in the neighborhood where they are to be used. Both concrete and steel poles may be transported in small packages over mountains and erected on the spot, but in this respect steel is much superior to concrete. Concrete poles are classified according to the horizontal load which may be applied to the pole 2 ft. from the top:

Class	*A*	*B*	*C*	*D*	*E*
Horizontal load applied 2 ft. from top, lb.	4,000	3,000	2,000	1,500	1,000

16. Depth to Set Poles in the Ground.—One rule is that they should, on straight lines, be set in the ground one-sixth of their lengths. The following table indicates good practice for normal soils.

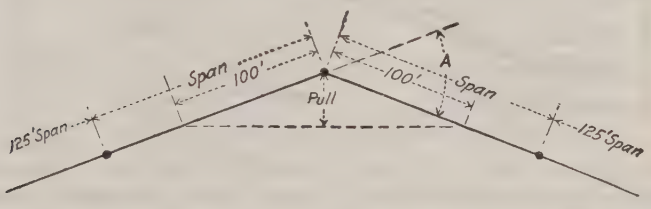
Pole length, over all, ft.	Depth to set in ground, ft.		Pole length, over all, ft.	Depth to set in ground, ft.	
	Straight lines	Curves, corners, and points of extra strain		Straight lines	Curves, corners, and points of extra strain
30	5.5	6.0	55	7.0	7.5
35	6.0	6.5	60	7.5	8.0
40	6.0	6.5	65	8.0	8.5
45	6.5	7.0	70	8.0	8.5
50	7.0	7.5	75	8.5	9.0

17. The size of pole to use cannot be definitely specified without knowing local conditions. Municipal ordinances sometimes regulate the heights of poles and wires. Where there are trees along the line, the wires should be carried entirely above them or through the lower branches, which interfere less than do the higher ones where the foliage is thicker. (See Sec. **74A** for required clearances of wires above the ground.) For lines on highways it is usually customary to place the lowest wire at least 18 ft. above the highway, and 21 ft. is better. Railway companies frequently specify 22 ft. between the top of the rail and the lowest crossarm. Wires should be at least 15 ft. above sidewalks. The height of the pole will depend upon the number of crossarms to be carried. It is desirable to avoid abrupt changes in the level of wire. Hence, where the line runs up hill and down dale, the longer poles should be used in the valleys.

Guy wires should, except where otherwise provided by ordinance, be at least 18 ft. above a highway and 12 ft. above a sidewalk.

Also in cities it is good practice to use 35-ft. poles to carry either one or two crossarms; 40-ft. poles to carry three or four crossarms; and 45-ft poles to carry over four crossarms. For suburban lines 30-ft. poles are often used. For very light lines carrying only three of four wires, 6-in. poles 25 ft. long are sometimes used, though so light a pole is inexpedient if the number of wires is likely to increase. The height of a pole is always considered as the total length over all.

18. Poles should be spaced, in straight portions of a line, about 125 ft. apart. The usual maximum is 150 ft., and the minimum about 100 ft. In curves and at corners the spans should be about as indicated in Fig. 5. For rural lines the span may be lengthened to 200 or 250 ft. Spans



Note: If the "Pull" is less than 5', the Spans Adjacent to the Angle Pole shall be Standard length (125'). If the "Pull" exceeds 5', the Spans Adjacent to the Angle Pole shall be Reduced to the Distance "Span" Given in Table.

Angle A.	Pull in feet.	Span	No of 6000 lb. Side Guys.		
			1 Arm 6 Wires.	2 Arms 12 Wires.	3 Arms 18 Wires.
Less than 6°	Less than 5'	125'	None	None	None
6°–11°	5'–10'	115'	None	1	1
11°–15°	10'–13'	105'	1	1	1
15°–22°	13'–19'	95'	1	1	2
22°–30°	19'–26'	85'	1	1	2
Over 30°	Over 26'	75'	1	2	2

FIG. 5.—Pole spacing and side guys on curves. (*National Electric Light Association.*)

up to 400 or 500 ft. have been used for rural feeder lines employing aluminum cable, steel-reinforced.

19. Holes for poles should be large enough to admit the poles without any slicing or chopping and should be of the same diameter from top to bottom. The diameter of the hole should always be at least large enough so that a tamping bar can be worked on all sides between the pole and the sides of the hole.

20. Setting Poles.—On straight lines poles should be set perpendicularly. On curves, poles should slant slightly so that the tension of the wires will tend to straighten them. In filling a hole after the pole is in it, only one shoveler should be employed and as many more men as can conveniently work around the pole should tamp in the earth as the shoveler throws it in. Some of the surplus earth should be piled around the butt of the pole so the water will drain away. Figure 6 illustrates the method of setting a pole with pikes.

21. Setting Poles with a Gin Pole.—A few men can set a large pole with a gin pole as suggested in Fig. 7. The gin pole can be a short wooden pole or, where the poles to be raised are not too heavy, a length of

wrought-iron pipe. The gin need be only one-half as long as the pole to be raised. In setting a pole the gin is first raised to an almost vertical position with its top over the pole hole. It is held in that position by fastening the guy lines. Then the hook of the tackle blocks is engaged in a sling around the pole and the pole is raised, by men or by a team of

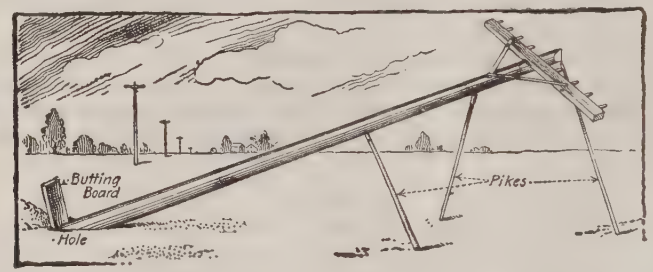


FIG. 6.—Method of setting a pole with pikes.

horses, by pulling on the free end of the tackle block line. When high enough so that its lower end can be slipped into it, the pole is dropped into the hole and adjusted to a vertical position with pikes, and the earth is tamped in. Sometimes gin poles are permanently mounted on wagons for transportation and are then called pole derricks. They are great savers of time and money.

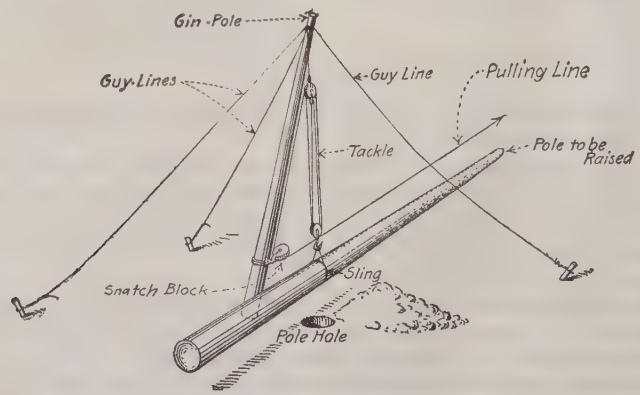


FIG. 7.—Gin pole for raising poles.

22. Setting Poles in Loose and Weak Soils.—On important lines it is customary to use a concrete setting for the pole (Fig. 8, I). A suitable mixture is 1 part cement, 3 parts sand, and 3 parts of broken stone or coarse gravel.

For somewhat less important lines where the soil is fairly firm the sand barrel (Fig. 8, II) is a valuable expedient. This consists of a strong

barrel or barrels placed at the bottom of the hole into which the pole is set. The barrel is filled with a firm substantial soil. By this means the pole is given a larger bearing area. Sometimes a temporary sand barrel is used, consisting of a special iron cylinder that is placed around the pole, filled with firm dirt, and then hoisted away.

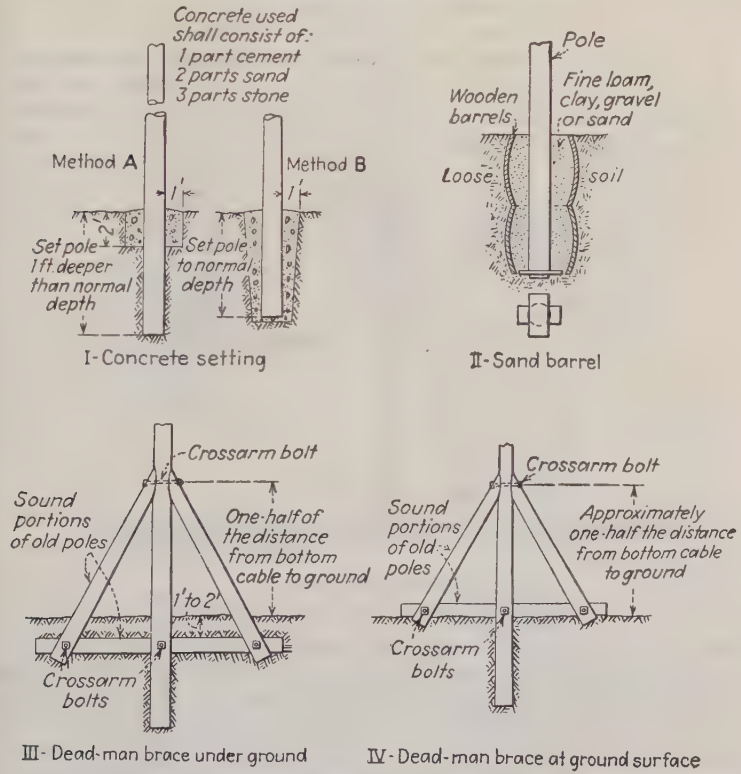


FIG. 8.—Methods of setting poles in poor soils. (*General Electric Co.*)

In marshy ground another expedient for less important lines is to build a triangular brace from sound portions of old poles (Fig. 8, III and IV) bolted together. This provides a bearing area on or near the top of the soil which resists overturning of the pole. The method of Fig. 8, III, is preferable to the one in Fig. 8, IV, because the ground member will not rot so fast when it is completely underground. There is, however, somewhat more labor involved in digging the trench for the ground member. These methods are not so permanent as a concrete foundation and are recommended only where the expense of a concrete foundation does not seem warranted.

23. When setting poles in rock the hole may be blasted, or a hole 1½ in. in diameter may be drilled in the rock (Fig. 9) in which is placed an iron pin that extends about 6 in. above the surface. A similar hole is drilled in the butt of the pole, and the pole mounted on the pin. It must then be braced by three or four wood struts spiked to the pole 6 ft. from the ground, running diagonally to the rock and formed thereto, or it may be braced by guy wires made fast to metal pins set in the rock.

24. Wooden poles which have rotted at the butt can be reinforced with a short stub pole set in the ground next to the regular pole and extending a few feet above the ground line. Various methods of stubbing are shown in Fig. 10, with the required materials in Fig. 11. In all cases

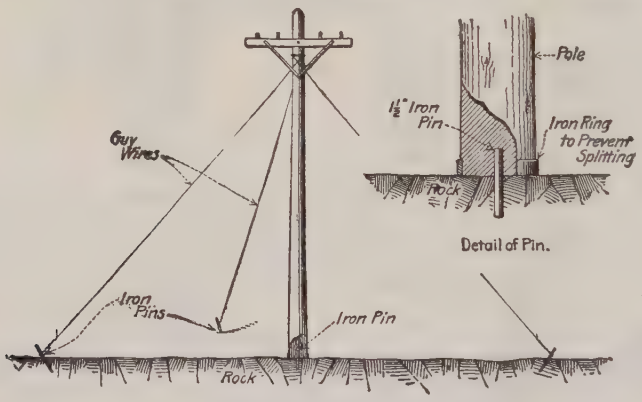


FIG. 9.—Method of setting pole on rock.

two bands should be employed with spacings as given below. In Fig. 10 only the top band of the two is illustrated in several cases. Where a wire wrap is employed (Fig. 10, *C*) four wraps should be made around the pole and six wraps around both the pole and stub for poles up to 40 ft. long. For poles longer than 40 ft. 10 wraps should be used around both pole and stub. In employing the method of Type *C*, Fig. 10, the following dimensions should be used: Dimension *C* should be not less than 30 in. for poles up to 45 ft. long or 36 in. for poles from 45 to 50 ft. long; dimension *A* should be not less than 38 in. for poles up to 45 ft. long or 44 in. for poles from 45 to 50 ft. long; dimension *B* should be not less than 24 in. for poles up to 45 ft. long or 30 in. for poles from 45 to 50 ft. long. Poles are generally stubbed so that the stub is across the line. Methods *D* and *E* will not be satisfactory if the stub is located along the line. The other methods can be used for either across-the-line or along-the-line stubbing. With method *B* the ⅝-in. dowels are not required if the poles are stubbed across the line.

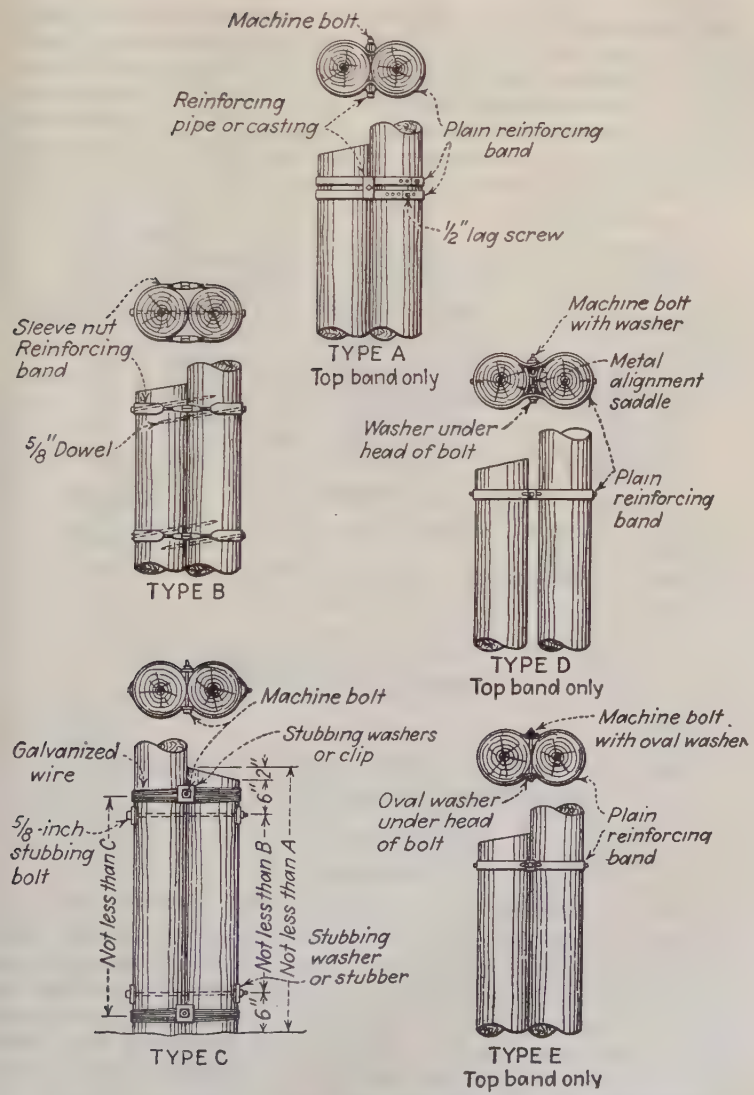


FIG. 10.—Methods of reinforcing with stubs. (*Hubbard & Co.*)

25. Reinforcing Old Poles with Concrete and Steel.—Wooden poles usually become unsafe because of butt rot at the ground line. Such poles can be repaired without moving the wires they support by reinforcing them with steel and concrete as shown in Fig. 12. For ordinary poles and conditions, 10 mild-steel rods ½ in. in diameter and 4 to 6 ft. long are used for reinforcing. The lower end of each reinforcing rod is pointed and is driven into the portion of the butt that remains

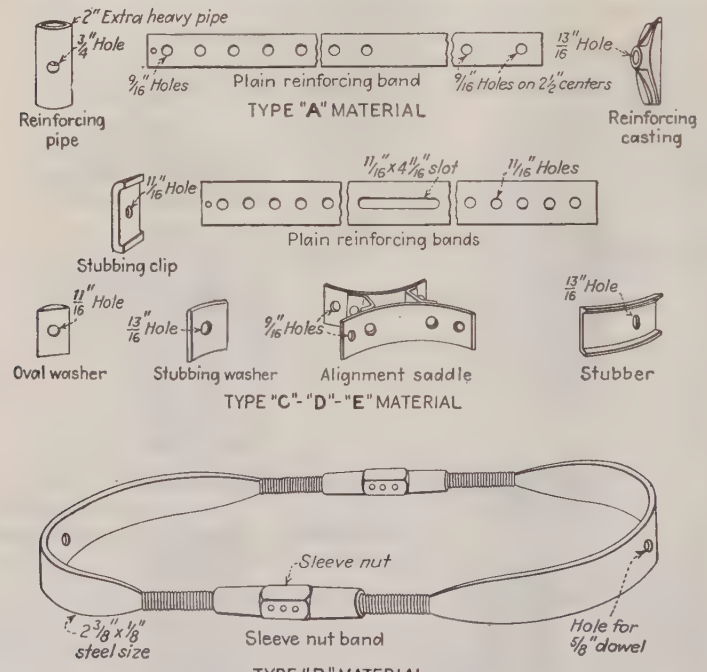


FIG. 11.—Materials for reinforcing with stubs. (*Hubbard & Co.*)

in the hole. The other end is bent at right angles, and pointed. It is driven into the pole above the ground line. A 1:2½:5 mixture of concrete is used for the main body, and a richer mixture is used for the portion above ground line and is molded in a cylindrical sheet-iron form. The concrete extends to about 1½ ft. above the ground line. Poles 15 to 20 years old have been satisfactorily repaired by this method without moving the wires supported.

26. Repairing Steel Poles.—Metal poles sometimes corrode very rapidly at the ground, and often when discovered the corrosion is too far advanced to make any preventive measures effective. A very satisfactory method (Fig. 13) of repairing steel poles is to place a loose-fitting metal sleeve around the butt of the pole and fill the space between the two with Portland cement.

27. Crossarm bolts are used for fastening crossarms to the poles. These bolts are standard $\frac{5}{8}$-in. galvanized machine bolts. See machine-bolt data in Div. 4 for dimensions. A square washer is used under both head and nut as shown in Figs. 47, 60, and 70, I.

28. Double-arming bolts (Fig. 14) give a more rigid construction and greater economy than the old block-spacer method of tying two cross

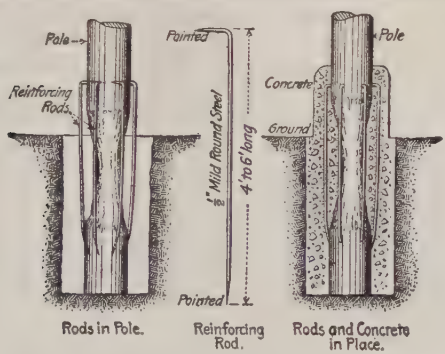


FIG. 12.—Reinforcing pole with concrete.

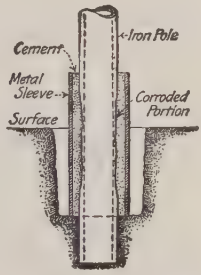


FIG. 13.—Repairing metal pole.

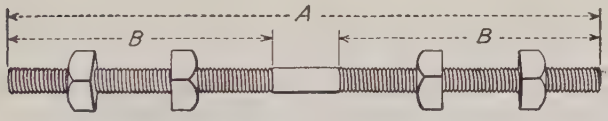


FIG. 14.—Double-arm bolts. (*Line Material Co.*)

arms together. The double-arming bolts are furnished with a long rolled thread, galvanized and fitted with four square nuts. A square washer is used under each nut as shown in Figs. 48, 68, III, and 70, II.

Diam. of bolt, in.	*A*, in.[a]	*B*, in.[a]	Diam. of bolt, in.	*A*, in.[a]	*B*, in.[a]
	12	6		12	5
	14	6		14	6
	16	8		16	8
½	18	8	¾	18	8
	20	8		20	8
	22	8		22	8
	24	8		24	8
	12	6			
	14	6			
	16	6			
⅝	18	8			
	20	8			
	22	8			
	24	8			

[a] Refer to Fig. 14.

29. Eyebolts (Fig. 15) are furnished with forged oval eye, rolled threads, and square nut, galvanized. Eyebolts are used for fastening guys, dead-ending insulators, and suspension insulators to crossarms, as shown in Figs. 41, I; 87; and 88. A square washer is used under nut and eye.

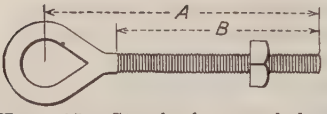


FIG. 15.—Standard eye bolt. (*Line Material Co.*)

Diam. of bolt, in.	Opening in forged eye, in.	*A*, in.	*B*, in.	Diam. of bolt, in.	Opening in forged eye, in.	*A*, in.	*B*, in.
½	1¼ × 1½[a]	6	3	¾	1½ × 2	6	4
	1¼ × 1½[a]	8	4		1½ × 2	8	4
	1¼ × 1½[a]	10	4		1½ × 2	10	4
	1¼ × 1½[a]	12	4		1½ × 2	12	4
	1¼ × 1½[a]	14	6		1½ × 2	14	6
	1¼ × 1½[a]	16	6		1½ × 2	16	6
	1¼ × 1½[a]	18	6		1½ × 2	18	6
	1¼ × 1½[a]	20	6		1½ × 2	20	6
⅝	1½ × 2	6	3				
	1½ × 2	8	4				
	1½ × 2	10	4				
	1½ × 2	12	4				
	1½ × 2	14	6				
	1½ × 2	16	6				
	1½ × 2	18	6				
	1½ × 2	20	6				
	1½ × 2	22	6				
	1½ × 2	24	6				

30. Double-arming eyebolts (Fig. 16) are furnished with forged oval eye and 3 square nuts, galvanized. Opening of eye is 1½ × 2 in. They are used for the same purposes as eyebolts in double-arm construction (see Figs. 41, IV; 48; and 86). Thimble-eye, double-arming bolts are also available which eliminate the use of a separate thimble in attaching guy wires to the eye of the bolt.

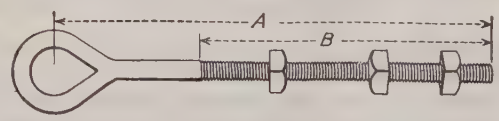


FIG. 16.—Double-arming eye bolt. (*Line Material Co.*)

Diam. of bolt, in.	*A*, in.	*B*, in.	Diam. of bolt, in.	*A*, in.	*B*, in.
⅝	16	12	¾	20	16
	18	14		22	18
	20	16		24	20
	22	18			
	24	20			

31. Eye nuts (Fig. 17) are used on through bolts, eyebolts, double-arming bolts, straight and angle thimble-eye bolts, crossarm bolts,

anchor rods, and for other attachments where it is desired to convert a standard threaded bolt to a thimble-eye bolt. They are commonly used for dead-ending a messenger wire or span guy on the threaded end of an angle thimble-eye bolt on the opposite end of which is a down guy.

There are two types of eye nuts: (1) the standard eye (Fig. 17, V), which requires the use of a thimble, and (2) the thimble-eye, which has a thimble forged in it. The thimble-eye type is also made in a twin style (Fig. 17, II) to take two guy strands, and in a three-guy-eye style (Fig. 17, III) to take three guy strands. The guy eye (Fig. 17, I) serves the same purpose as the thimble-eye, merely being forged in a slightly different manner. Refer to Fig. 70, II for application.

FIG. 17.—Eye nuts. (*Hubbard & Co.*)

32. Common or buttonhead carriage bolts are used for attaching crossarm braces to crossarms. They are provided with a square shoulder under the head. A round washer is used under the head, as shown in Figs. 47 and 60.

FIG. 18.—Carriage bolt.

Diam., in.	Length, in.	Length of thread, in.	Approx. shipping weight, lb. per 100 pieces	Diam., in.	Length, in.	Length of thread, in.	Approx. shipping weight, lb. per 100 pieces
	3	1¾	14.5		3	2½	26.7
	3½	1¾	16.5		3½	3	29.2
	4	1¾	18.3		4	3	33.3
⅜	4½	1¾	20.0		4½	3	36.7
	5	1¾	21.1		5	3	38.6
	5½	1¾	22.5		5½	3	41.2
	6	1¾	23.3	½	6	3	44.0
					7	3	50.0
					8	4	59.0
					10	4	72.0
					12	6	85.0
					14	6	99.0
					16	6	105.0

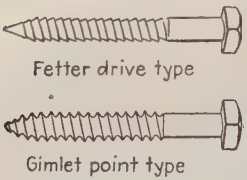


FIG. 19.—Lag screws.

33. Lag screws are made in both the fetter-drive and gimlet-point types. The ¼- and 5/16-in. screws are generally of the gimlet-point type, while all screws of larger diameter are generally of the fetter-drive type. Lag screws are used for attaching crossarm braces to poles, as shown in Figs. 47, 50, and 60.

Diam., in.	Length, in.	Length of thread, in., and type	Approx. shipping weight, lb. per 100 pieces	Diam., in.	Length in.	Length of thread, in., and type	Approx. shipping weight, lb. per 100 pieces
¼	1½	1⅛ G.P.	2.0	½	2½	2 F.D.	18.4
	2	1⅝ G.P.	3.5		3	2½ F.D.	20.9
	2½	1¾ G.P.	5.0		3½	3 F.D.	23.4
	3	2 G.P.	6.5		4	2½ F.D.	26.0
	4	2½ G.P.	8.0		4½	2⅞ F.D.	27.8
5/16	2	1¾ G.P.	5.2		5	3¼ F.D.	32.1
	2½	2 G.P.	6.2		5½	3 F.D.	33.9
	3	2¼ G.P.	7.5		6	3 F.D.	38.3
	3½	2½ G.P.	9.7		6½	2⅞ F.D.	43.2
	4	2½ G.P.	11.9		7	3 F.D.	46.4
⅜	2¼	2 F.D.	8.8	⅝	4	3 F.D.	42.6
	2½	2 F.D.	9.7		4½	3 F.D.	46.0
	3	2 F.D.	11.0		5	3½ F.D.	50.6
	3½	2½ F.D.	12.8		5½	3 F.D.	55.2
	4	2⅞ F.D.	14.6		6	2⅞ F.D.	60.0
	4½	3 F.D.	16.4	¾	5	3 F.D.	74.5
	5	3 F.D.	16.9		6	3½ F.D.	84.9
	6	3 F.D.	19.9		7	4 F.D.	99.4
					8	4½ F.D.	112.2

34. Lag-screw eyes (Fig. 20) are galvanized and furnished with gimlet point, lag-screw thread. The forged eye has a 1¼- by 1½-in. opening.

35. Washers used in overhead line construction are made of galvanized iron in both round and square types. Square washers are used under the heads and nuts of all crossarm bolts. Round washers are used under the heads of carriage bolts which fasten crossarm braces to crossarms.

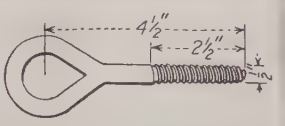


FIG. 20.—Lag-screw eye. (*Line Material Co.*)

Outside diam., in.	Size of hole, in.	Thickness, in.	Size of bolt, in.		Dimensions, in.	Diam. of hole, in.	Size of bolt, in.
			Mach.	Carriage			
1	7/16	5/64	⅜		2 × 2 × ⅛	1 1/16	½ or 5/8
1¼	½	5/64	..	⅜	2¼ × 2¼ × 3/16	1 3/16	5/8 or ¾
1⅜	9/16	7/64	½	⅜	3 × 3 × 3/16	1 3/16	5/8 or ¾
1¾	11/16	⅛	5/8	½	3 × 3 × ¼	1 3/16	5/8 or ¾
2	13/16	⅛	¾	5/8	4 × 4 × 3/16	1 3/16	5/8 or ¾
					4 × 4 × ¼	1 5/16	¾ or ⅞
					4 × 4 × ½	1 13/16	1
					3½ × 3½ × ⅜	1 5/16	¾ or ⅞
					6 × 6 × ⅜	1 13/16	1

36. Standard Wooden Crossarms

(General Electric Supply Co.)

Pin holes				Center bolt hole, in.	Brace length, in.	Size and length
Spacings, in.			Size, in.			
Center	Sides	Ends				
Electric Light Arms						3¼ × 4¼
28	....	4	1 17/32	5/8	25	3 ft. 2 pin
16	12	4	1 17/32	5/8	28	4 ft. 4 pin
18	17	4	1 17/32	5/8	28	5 ft. 4 pin
22	21	4	1 17/32	5/8	32	6 ft. 4 pin
16	12	4	1 17/32	5/8	32	6 ft. 6 pin
18	17½	4	1 17/32	5/8	32	8 ft. 6 pin
16	12	4	1 17/32	5/8	32	8 ft. 8 pin
16	9¾	4	1 17/32	5/8	32	8½ ft. 10 pin
17½	15¾	4	1 17/32	5/8	42	10 ft. 8 pin
16	12	4	1 17/32	5/8	42	10 ft. 10 pin
16	9⅝	3⅞	1 17/32	5/8	42	10 ft. 12 pin
R.S.A. Arms						3 × 4¼
20	22	4	9/16	1 1/16	..	6 ft. 4 pin
19	17¼	4	9/16	1 1/16	..	8 ft. 6 pin
19	15½	4	9/16	1 1/16	..	10 ft. 8 pin
16	12⅜	2½	9/16	1 1/16	..	10 ft. 10 pin
Western Union Arms						3 × 4¼
20	11½	3	9/16	21/32	..	6 ft. 6 pin
21	11½	3	9/16	21/32	..	8 ft. 8 pin
22	11½	3	9/16	21/32	..	10 ft. 10 pin
Pony Telephone Arms						2¾ × 3¾
17	....	3½	1 9/32	5/8	..	24 in. 2 pin
23	....	3½	1 9/32	5/8	..	30 in. 2 pin
29	....	3½	1 9/32	5/8	25	36 in. 2 pin
16	9½	3½	1 9/32	5/8	28	42 in. 4 pin
16	9¾	3½	1 9/32	5/8	28	62 in. 6 pin
16	9¾	3¾	1 9/32	5/8	28	82 in. 8 pin
16	9¾	4	1 9/32	5/8	28	102 in. 10 pin
16	9⅝	3⅞	1 9/32	5/8	28	120 in. 12 pin
N.E.L.A. Arms						3½ × 4½
30	....	4	1 17/32	1 1/16	28	3 ft. 2 in. 2 pin
30	14½	4	1 17/32	1 1/16	38	5 ft. 7 in. 4 pin
30	14½	4	1 17/32	1 1/16	38	8 ft. 6 pin
30	12	4	1 17/32	1 1/16	38	9 ft. 2 in. 8 pin
N.E.L.A. (Light) Arms						3¼ × 4¼
30	....	4	1 17/32	1 1/16	28	3 ft. 2 in. 2 pin
30	14½	4	1 17/32	1 1/16	38	5 ft. 7 in. 4 pin
30	14½	4	1 17/32	1 1/16	38	8 ft. 6 pin
30	12	4	1 17/32	1 1/16	38	9 ft. 2 in. 8 pin
New England Arms						3¼ × 4¼
30	....	3	1 17/32	1 1/16	33	3 ft. 2 pin
30	13½	4½	1 17/32	1 1/16	36	5 ft. 6 in. 4 pin
30	13½	4½	1 17/32	1 1/16	36	7 ft. 9 in. 6 pin
30	13½	4½	1 17/32	1 1/16	36	10 ft. 8 pin
New England Power Arms						3¾ × 4¾
30	....	3	1 17/32	1 1/16	33	3 ft. 2 pin
30	13½	4½	1 17/32	1 1/16	36	5 ft. 6 in. 4 pin
30	13½	4½	1 17/32	1 1/16	36	7 ft. 9 in. 6 pin
30	13½	4½	1 17/32	1 1/16	36	10 ft. 8 pin
Pacific Arms						3¼ × 4¼
28	....	4	1 17/32	5/8	32	3 ft. 2 pin
28	12	4	1 17/32	5/8	32	5 ft. 4 pin
28	12	4	1 17/32	5/8	32	7 ft. 6 pin
28	12	4	1 17/32	5/8	42	9 ft. 8 pin
28	12	4	1 17/32	5/8	42	11 ft. 10 pin

37. Wooden crossarms are generally made of Douglas fir, which, according to tests made by the U.S. Forest Service, is best suited for

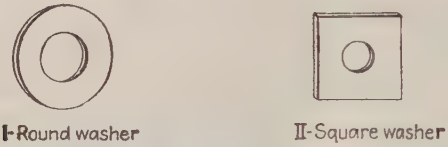


FIG. 21.—Washers.

the purpose. Longleaf yellow pine and Norway pine also are used for crossarms. Crossarm dimensions have not actually been standardized throughout the country. The dimensions of those carried as standard by one manufacturer are given in Sec. **36.** Great care should be exercised in ordering crossarms to give full specifications. It is generally best to furnish a sketch (Fig. 22) with accompanying dimensions for the required boring.

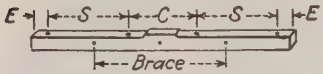


FIG. 22.—Sketch for boring of crossarm.

Figure 23 shows the dimensions of crossarms recommended by the National Electric Light Association. These arms have a spacing between center pins of 30 in., which is believed to provide a safe climbing space. Arms of the N.E.L.A. cross-sectional dimensions (Fig. 23) have

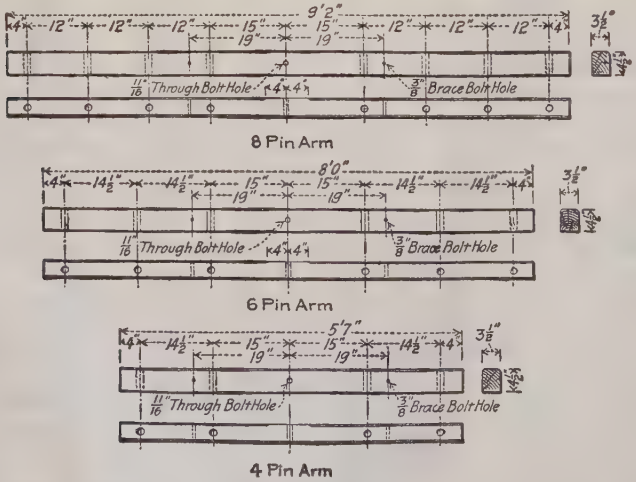


FIG. 23.—Crossarm dimensions recommended by the National Electric Light Association.

not come into extensive use. It is modern practice not to paint crossarms as soon as they are made. They either are treated with a wood preservative or are permitted to season naturally for at least 3 months

and are then painted with two coats of green white-lead paint before erection. Crossarms of Southern pine generally are pressure-treated against decay. It is not general practice to treat crossarms of other woods. No crossarm having a spacing of less than 20 in. between center pins or 12 in. between side pins should be used. The six-pin arm (Fig. 23) is recommended for general use.

38. Galvanized-steel crossarms are made from standard steel angles in three types, as given in Sec. **39**. They cost somewhat more than wooden crossarms but are more durable and will carry heavier loads. They are used for installations subjected to heavy strains and for higher voltage lines.

39. Types of Galvanized-steel Crossarms
(Hubbard & Co.)

Number of pins	Length, in.	Brace style	Pin spacing, in.		Size of angle, in.	Approximate shipping weight, lbs. per 100 pieces
			Pole pins	Side pins		
Telephone Arms—Pinholes, $1\frac{3}{16}$ In., Pole-mounting Hole, $1\frac{1}{16}$ In.						
2	20	Flat	16	....	$3 \times 2 \times \frac{3}{16}$	575
4	40	Flat	16	10	$3 \times 2 \times \frac{3}{16}$	1,125
6	60	Flat	16	10	$3 \times 3 \times \frac{1}{4}$	2,700
8	80	Flat	16	10	$3 \times 3 \times \frac{1}{4}$	3,600
10	100	Flat	16	10	$3 \times 3 \times \frac{1}{4}$	4,510
Electric-light Arms—Pinholes, $1\frac{3}{16}$ In., Pole-mounting Hole, $1\frac{1}{16}$ In.						
2	36	Flat	30	....	$3 \times 3 \times \frac{1}{4}$	1,625
4	65	Flat	30	$14\frac{1}{2}$	$3 \times 3 \times \frac{1}{4}$	2,915
6	94	Angle	30	$14\frac{1}{2}$	$3\frac{1}{2} \times 3\frac{1}{2} \times \frac{5}{16}$	6,215
8	$117\frac{3}{4}$	Angle	30	$13\frac{5}{8}$	$3\frac{1}{2} \times 3\frac{1}{2} \times \frac{5}{16}$	7,770
Power-transmission Arms—Pinholes, $1\frac{3}{16}$ In., Pole-mounting Hole, $1\frac{1}{16}$ In.						
2	28	Flat	24	....	$3 \times 3 \times \frac{1}{4}$	1,290
2	40	Flat	36	....	$3 \times 3 \times \frac{1}{4}$	1,840
2	52	Flat	48	....	$3 \times 3 \times \frac{1}{4}$	2,410
4	76	Angle	24	24	$3 \times 3 \times \frac{1}{4}$	3,490
2	80	Angle	74	....	$3\frac{1}{2} \times 3\frac{1}{2} \times \frac{5}{16}$	5,280
4	116	Angle	38	36	$3\frac{1}{2} \times 3\frac{1}{2} \times \frac{5}{16}$	7,645

40. Crossarm braces are made from galvanized flat strap iron (Fig. 24, I), ribbed strap iron (Fig. 24, II), or angle iron (Fig. 24, III). Braces are attached to the back of each crossarm by a carriage bolt with the head of the bolt at the front with a round washer under it (Figs. 47 and

60). The braces are secured to the pole with a through bolt or a lag screw. The flat type is used for ordinary loads. It is made in lengths varying in 2-in. increments from 20 to 32 in., the 28-in. length being the most common. The ribbed type, being about 25 per cent stronger, is used for heavier loads. The angle-iron type is used for very heavy lines. The standard sizes are given in Table 41, the first four being the Edison Electric Institute standard for power-company use. The alley-arm brace (Fig. 25, II) is used to support alley-type crossarms (see Sec. **62**). The vertical brace (Fig. 25, III) supports the upper crossarms from the lowest crossarm in alley-arm construction (Fig. 49). The back brace (Fig. 25, IV) is fastened at the back of the crossarm and on the back of the pole. It is used as an alternative to double-arm construction at crossings and at abrupt turns in the line. A back brace for alley arms is shown in Fig. 25, I.

41. Angle Crossarm Braces[a]
(Hubbard & Co.)

Angle size	Dimensions, in. A	B	C	Approx. shipping weight, lb. per 100 pieces
1½ × 1½ × 5/16	45	42	12	858
1½ × 1½ × 5/16	51	48	18	1,067
1½ × 1½ × 5/16	63	60	18	1,210
1¾ × 1¾ × 5/16	75	72	22	1,716
1½ × 1½ × 5/16	51	48	14	974
1½ × 1½ × 5/16	40	37	12	781
1½ × 1½ × 5/16	51	48	14¾	979
1¾ × 1¾ × 5/16	63	60	18	1,408
1¾ × 1¾ × 5/16	69	66	20	1,551
1¾ × 1¾ × 5/16	75	72	18	1,639
2 × 2 × 5/16	75	72	22	1,958

[a] Refer to Fig. 24, III.

42. Crossarm Back Braces (Fig. 25, IV)

Angle size, in.	Length over all, in.	Approx. shipping weight, lb. per 100 pieces	Angle size, in.	Length over all, in.	Approx. shipping weight, lb. per 100 pieces
1½ × 1½ × 5/16	48	550	1¾ × 1¾ × 5/16	94	1,540
1½ × 1½ × 5/16	60	825	1¾ × 1¾ × 5/16	109	2,204
1½ × 1½ × 5/16	72	1,200			

43. Insulators are used for insulating the electrical conduction wires and guy wires from the pole structure. The different types may be classified as pin, suspension, spool, strain, and wireholder insulators. Either pin-type (Fig. 26) or suspension-type insulators (Fig. 30) are used

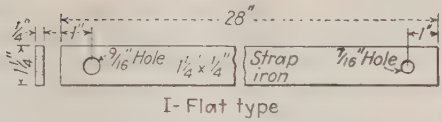


FIG. 24.—Standard crossarm braces. (*Hubbard & Co.*)

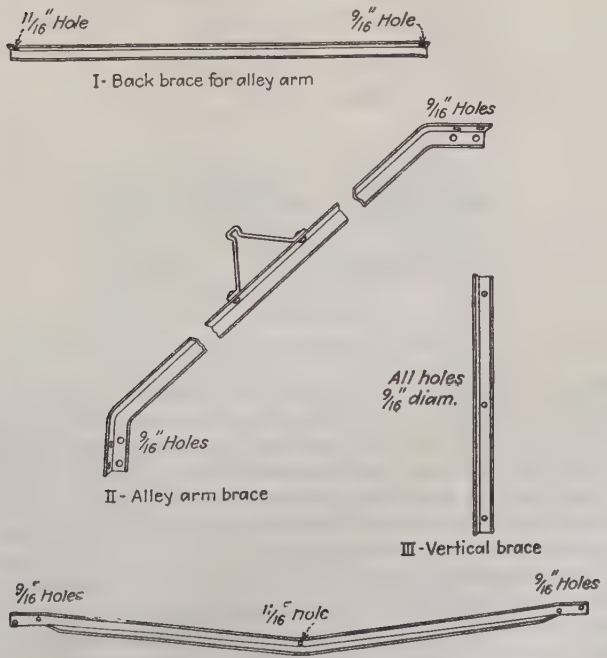


FIG. 25.—Special types of crossarm braces. (*Hubbard & Co.*)

for supporting the wires of the main electrical circuits. Spool insulators (Fig. 32) are used principally in the assembly of insulator racks (Fig. 33) for supporting low-voltage distribution mains from the sides of poles or buildings. Combined with a clevis, they are sometimes used for dead-ending low-voltage main electrical circuits. Strain insulators are used principally for insulating guy wires from the pole structure so that contact with the lower portion of the guy will not be dangerous. One type of porcelain strain insulator is frequently used for dead-ending low-voltage main electrical circuits or distribution wires. Wire-holder-type insulators are used in various assemblies for supporting service wires on

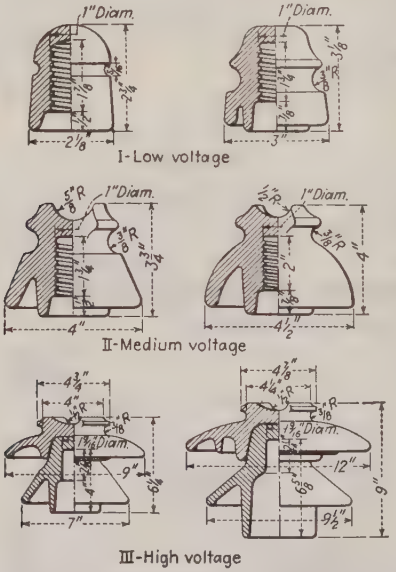


Fig. 26.—Typical pin-type insulators. (*Locke Insulator Corp.*)

buildings and for supporting, on the pole structure, taps for street-lighting luminaires (Fig. 148). Insulators are made of either glass or porcelain, the choice for any particular size and voltage being determined by weighing the electrical and mechanical characteristics against first cost. Glass has been most commonly used for pin insulators (Fig. 26, I) for voltages up to 5,000 volts. Porcelain has been most commonly used for pin insulators for higher voltages and for the other types of insulators.

44. Pin-type insulators are molded with a central threaded hole so that the insulator is supported from threaded insulator pins mounted on the crossarms. These insulators are made in various shapes and with varying contours to meet the insulating requirements for different

voltage classifications. For low-voltage work the insulators are generally grooved on the side for support of the wires. Medium-voltage insulators frequently have wire grooves on both top and sides and the higher voltage ones are made with only top grooves. Typical pin-type insulators are shown in Fig. 26.

45. Insulator Pins.—Pin insulators of the type shown in Fig. 26 are fastened on crossarms with insulator pins which thread into the cast

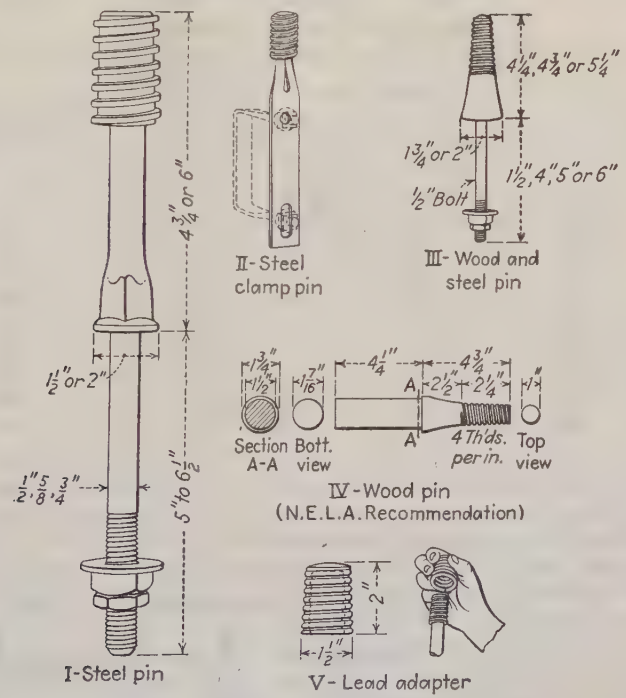


Fig. 27.—Insulator pins. (*Line Material Co.*)

thread inside the insulator. Insulator pins may be wood, steel, steel and lead, or steel and wood (Fig. 27). The wood pins (Fig. 27, IV) are made from oak or locust, the locust being preferred as less apt to crack. Wood pins are used on communication circuits and low-voltage distribution circuits on account of their low cost. Steel pins (Fig. 27, I and II) are used on the higher voltage, longer span lines where the side loads on the pin are greater. Combination wood-cob-with-steel-bolt pins (Fig. 27, III) provide stronger construction than the plain wood at lower cost than all-steel pins. Lead adapters (Fig. 27, V) may be used with 1-in. steel pins to fit 1⅜-in. insulator threads.

46. Wooden Insulator Pins.—All standard insulator pins of 1- and 1⅜-in. top diameter have four threads to the inch and a tapering diameter of $\frac{1}{16}$-in. increase for each inch in length.

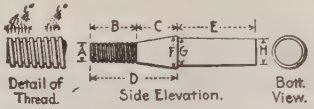


FIG. 28.—Wooden insulator pin.

Dimensions, in.								Shipping weight per 1,000, lb.
A	*B*	*C*	*D*	*E*	*F*	*G*	*H*	
1	2½	2¼	4¾	4¼	1¾	1½	1 7/16	400
1	2½	4¾	7¼	4¼	2	1½	1 7/16	510
1	2½	4¾	7¼	4¼	2¼	1¾	1 11/16	700
1	2½	4	6½	5	2½	2	1 15/16	930
1⅜	2¼	2½	4¾	4¼	1⅞	1½	1 7/16	400
1⅜	2¼	5	7¼	4¼	2	1½	1 7/16	510
1⅜	2¼	5	7¼	4¼	2¼	1¾	1 11/16	700
1⅜	2¼	4¼	6½	5	2½	2	1 15/16	930
1⅜	2¼	7¼	9½	5	3	2	1 15/16	1,160
1⅜	2¼	8¾	11	5	3½	2	1 15/16	1,280
1⅜	2¼	9¾	12	5	3½	2	1 15/16	1,360

47. Wood pins are held in crossarms with a sixpenny nail as shown in Fig. 29. The nail should not be driven entirely in. Enough of its length should extend so that the cutting jaws of a pair of pliers can be forced under the head and the nail thereby withdrawn. If this suggestion is followed and it is necessary to remove a pin, it can be readily accomplished.

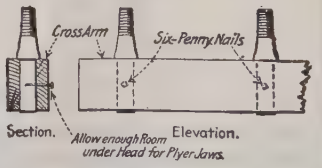


FIG. 29.—Fastening pin in crossarm.

48. Steel pins are either clamped over the crossarm as in Fig. 27, II, or the rod projects through a hole in the crossarm and is held in place with a washer, square-head nut, and pal nut (Fig. 27, I). The clamp type does not weaken the crossarm by the drilling of the holes but is more expensive.

49. Suspension insulators are used to support wires from under crossarms. They are used on high-voltage lines where pin insulators would become large, expensive, and unwieldy and are sometimes used on lower voltage lines also. They are made in a number of different styles varying

in hardware and petticoat diameters. There are three general types of hardware; hook and clevis, ball and socket, and the tongue and clevis as illustrated in Fig. 30. The hook type (Fig. 30, I) is used principally

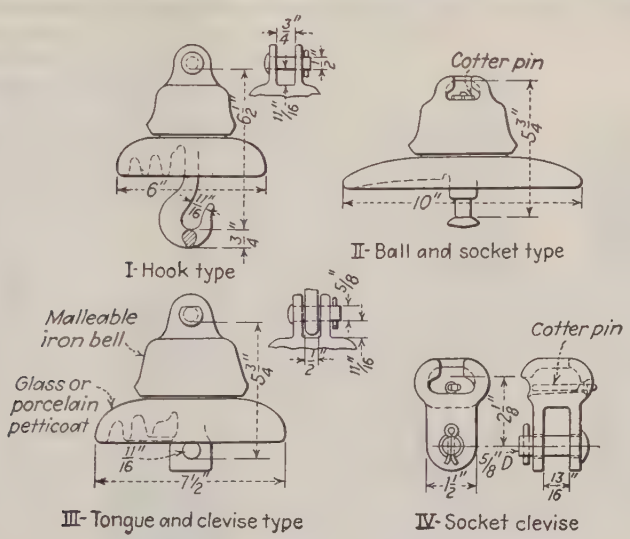


Fig. 30.—Suspension insulators. (*Locke Insulator Corp.*)

to support street-lighting units. Whether to use a ball-and-socket type (Fig. 30, II) or the tongue-and-clevis type (Fig. 30, III) on power circuits

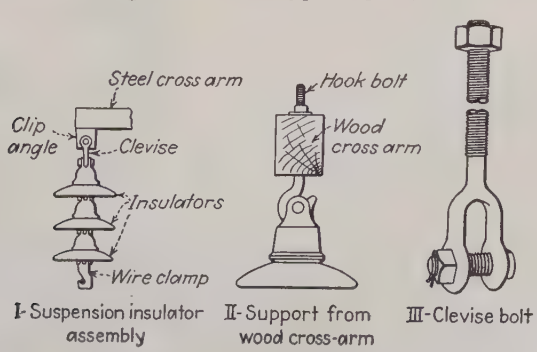


Fig. 31.—Details of suspension insulator supports.

is mostly a matter of individual choice. With the tongue-and-clevis type a round pin is used to hold the tongue of one unit in the clevis of the other. A cotter pin slips through a hole in the end of the round pin to

keep the pin from slipping out. With the ball-and-socket type the round pin is eliminated. The insulators are assembled by sliding the ball of one insulator into the socket of the next one from the side. A cotter pin is slipped in from the back of the socket, taking up sufficient space in the socket so that the ball cannot slide out. The socket clevis (Fig. 30, IV) is used where it is desired to support other hardware from the bottom of the insulator.

Suspension insulators are made up in strings as shown in Fig. 31. A clevis is used to support them from steel crossarms as shown in I. With wood crossarms a hook bolt through the crossarm may be used as in II or a clevis bolt as shown in III. The insulators are supported from each other with no additional hardware except the pins. The wire is supported from the bottom insulator with a wire clamp which is made in various types depending on the size of the wire. The voltage rating of a complete assembly is determined by the manufacturer from flashover tests. The diameter and shape of the petticoat and the number of units in the string affect the voltage rating. Small-diameter petticoats are preferred for locations where the insulators are subject to malicious damage from stones or bullets. The larger diameter units are ordinarily

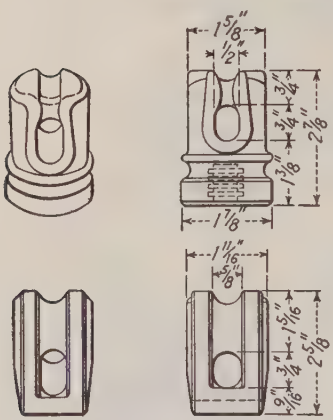


Fig. 32.—Typical spool- and wireholder-type insulators. (*General Electric Supply Corp.*)

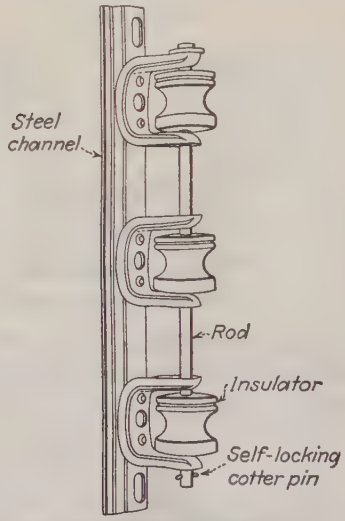


Fig. 33.—Low-voltage secondary rack. (*Line Material Co.*)

used on the longer strings on high-voltage lines, where the wires are at a greater height from the ground.

50. Spool- and wireholder-type insulators are used in single-wire or rack assemblies for supporting low-voltage circuits on the sides of poles

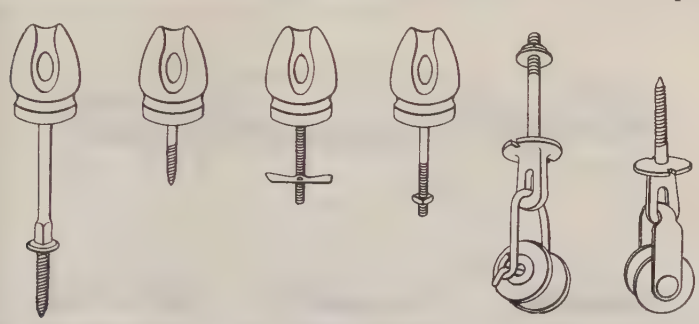


FIG. 34.—Typical single-wire insulator assemblies. (*General Electric Supply Corp.*)

and buildings and for dead-ending service wires on buildings, poles, and crossarms. In the rack assemblies (Fig. 33) the insulators are removable from the rack for easy replacement in case of breakage. The racks are made in two-, three-, and four-wire assemblies. Typical spool and wireholder insulator assemblies are shown in Figs. 32 to 35.

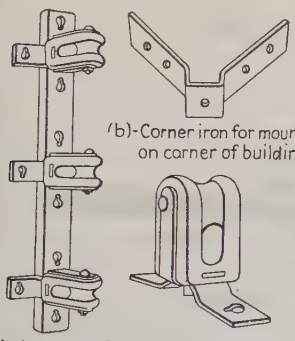
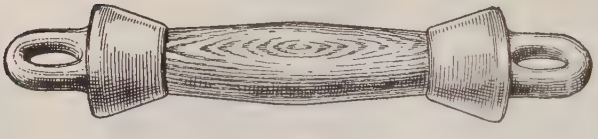


FIG. 35.—Typical wireholder rack assembly. (*General Electric Supply Corp.*)

51. Strain insulators are used in guys and are also used in line wires at dead-ending points. Composition, porcelain, and wooden strain insulators are made. Wooden strain insulators (Fig. 36) are popular with some companies and afford excellent insulation but have the objection that, if one burns, the wire that it supports falls. Composition and porcelain strain insulators can be made so that even if the insulating material fails, the supported wires will not fall. Figures 37 and 38 show types meeting these requirements. The strain insulator of Fig. 37 is cheap and satisfactory and has lately become very popular in electric-lighting-line construction.

52. Emergency strain insulators can be made by knocking the end out of common glass line-wire insulators as illustrated in Fig. 39. To break out the end, hold the insulator in one hand and strike the inside of the

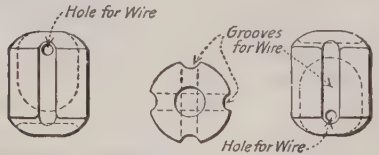
Construction Details.



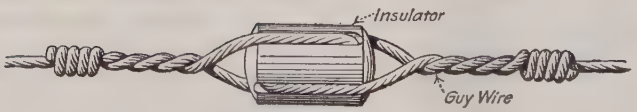
Two Eyes.

Eye and Clevis. Clevis and Tap. Two Clevises.

FIG. 36.—Wooden strain insulators.

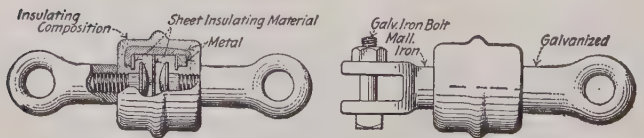


Details.



Insulator Installed

FIG. 37.—A strain porcelain insulator.



(Two Eyes) Construction Details. (Eye and Clevis) Complete Insulator.

FIG. 38.—Composition strain insulators.

top a sharp blow with the handle of a pair of pliers or of a pair of connectors or with a screw driver held in the other hand. Where one emergency insulator will not give sufficient insulation, two or more can be used in series. Emergency strain insulators thus made are not strong enough for heavy guy wires but are more suitable for insertion in line wires.

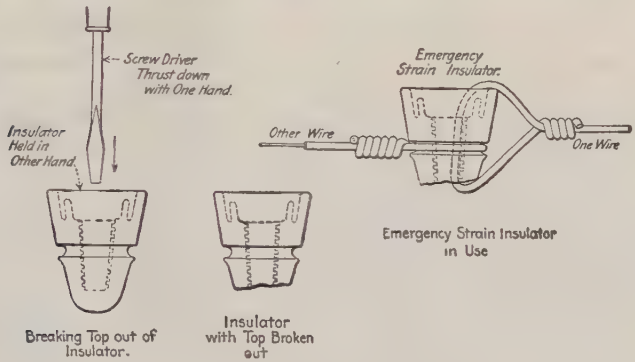


FIG. 39.—Emergency strain insulators.

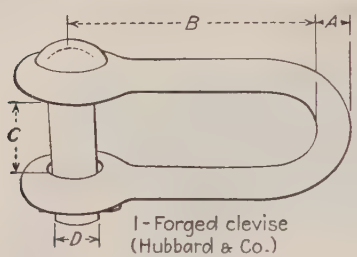
53. Clevises are used in making up assemblies connecting insulators, straps, strands, etc., together. Figure 40 illustrates some types of clevises. The forged clevises (Fig. 40, I) and bent strap clevises (Fig. 40, II) are used to connect dead-end insulators to crossarms (Fig. 41, I and II). The eye clevis (Fig. 40, III) will connect a dead-end insulator to another piece of hardware having a pin connection. The thimble clevis (Fig. 40, IV) will connect a stranded cable to an insulator assembly (Fig. 41, III). The strain-insulator clevis (Fig. 40, V) is used to connect a strain insulator of the type in Fig. 37 to an eyebolt or eye nut (Fig. 41, IV).

54. Guy anchor rods are used between the anchor in the ground and the guy strand. Figure 42, I, illustrates a roller type which allows the strand to turn on the rod and prevents twisting of the guy strand. Figure 42, II, is used to attach to a log anchor. Figure 42, III, is used when anchoring to solid rock or masonry. Guy anchor rods are made in ½-, ⅝-, ¾-, and 1-in. diameters.

55. In connecting a guy strand to the pole, the strand may be wrapped around the pole or may be connected to a special bolt. In wrapping the strand around the pole, guy hooks (Fig. 43, I) are used to prevent the strand from slipping down the pole, and guy plates (Fig. 44, II) or shims (Fig. 44, I) are placed under the guy strand to prevent its cutting into the pole. The molding strain plate of Fig. 44, III, is used under the guy-wire wrap on poles where a ground wire runs down the pole. The

plate will fit over N.E.L.A. standard 1-in. ground-wire molding and prevent the guy strand from cutting or crushing the ground-wire molding.

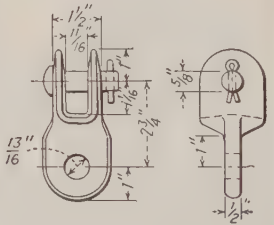
An alternative to this method is to connect the guy to a thimble-eye bolt. The straight thimble-eye type (Fig. 43, II) is used when guying



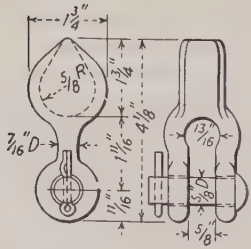
I - Forged clevise
(Hubbard & Co.)

Dimensions in inches				Approximate shipping weight lbs., 100 pcs.
A	B	C	D	
1/2	2	11/16	5/8	66
9/16	3	1 3/8	3/4	146
9/16	4	1 3/8	3/4	160
1/2	3	3/4	5/8	85

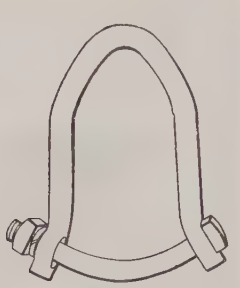
II - Bent strap clevise
(Line Material Co.)



III - Clevise eye
(Corning Glass Co.)



IV - Thimble clevise
(Ohio Brass Co.)



V - Strain Insulator Clevise
(Hubbard & Co.)

FIG. 40.—Clevises.

between a main pole and a stub pole. The angle thimble-eye type (Fig. 43, III) is used when guying into the ground. A J-bolt (Fig. 43, IV) may also be used for attaching a guy wire to a pole, but this requires the use of a thimble (Fig. 43, V) in addition to the bolt. A stubbing washer

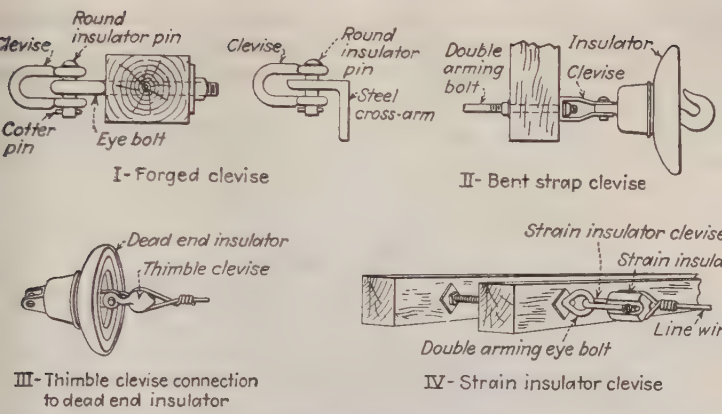


FIG. 41.—Applications of clevises to crossarm connections. (*Hubbard & Co.*)

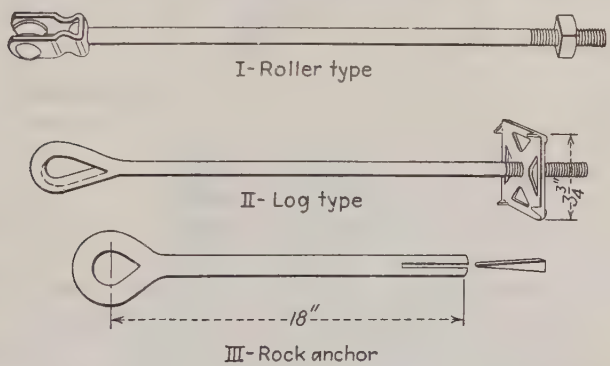


FIG. 42.—Guy anchor rods. (*Line Material Co.*)

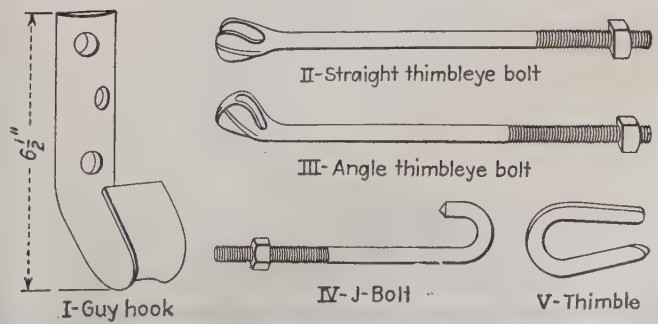


FIG. 43.—Guy hook, thimble-eye bolts, and J-bolt. (*Line Material Co.*)

should be used under the nut of the thimble-eye or J bolt. Under the eye of the bolt a stubbing washer (Fig. 44, V) is used for a 90-deg. guy and a guy plate of the type shown in Fig. 44, IV for an angle guy. Guying construction is discussed in Sec. **93.**

56. When connecting a guy strand to a bolt or rod of small diameter, the strand should be wrapped around a thimble (Fig. 43, V) to prevent its being cut or broken from too sharp a bend.

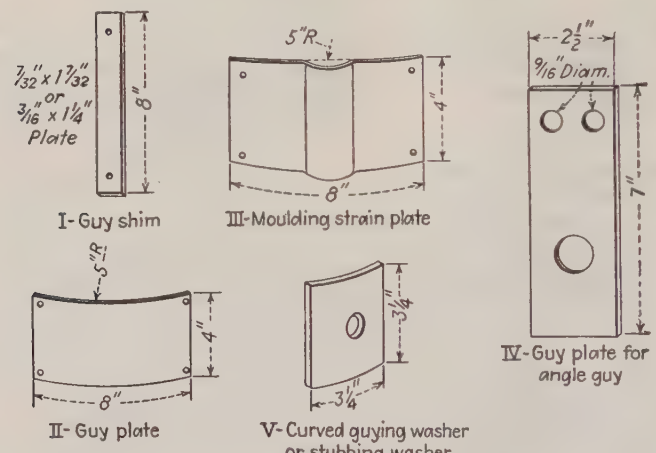


FIG. 44.—Guy plates and shims. (*Locke Insulator Corp. and Hubbard & Co.*)

57. Guy clamps (Fig. 45) are used for securing the ends of guy-wire strands. They are made in two-, three-, and four-bolt types.

Type	Length, In.
Two bolt, light	3
Two bolt, heavy	4
Three bolt, heavy	4
Three bolt, heavy	6
Three bolt, heavy	6
Four bolt, heavy	8

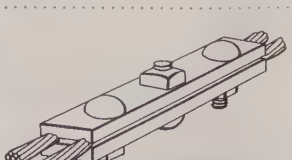


FIG. 45.—Guy clamp. (*Joslyn Manufacturing Co.*)

58. Guy protector guards are installed over guy rods, at locations where the guy might be damaged by traffic, to conceal the connection of the guy

strand to the eye of the guy rod, to make the guy more visible, and to minimize accidents. They may be made of a wood strip or of steel. One type of guard (Fig. 46) consists of a steel plate rolled into cylindrical form, leaving a split on one side. Special clamps are fastened to the strand, and the guard is slipped over the strand and held by the clamps. The

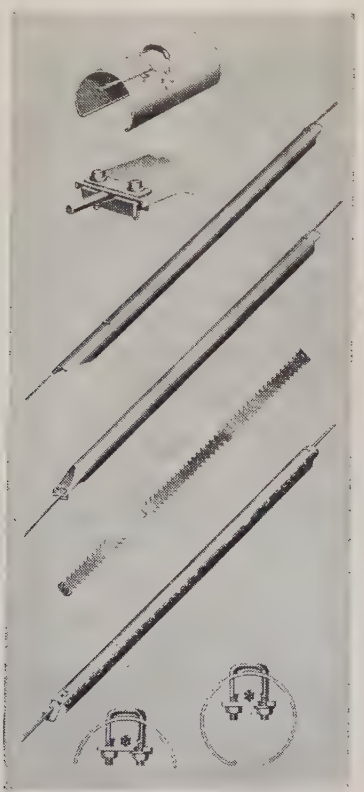


Fig. 46.—Guy protector guard. (*Line Material Co.*)

split is turned down toward the ground so that it is not ordinarily noticeable.

59. For guy wire, seven-strand, galvanized-steel cable is used. The National Electrical Safety Code recommends that for Grades A and B construction the maximum load in the guy should not exceed 50 per cent of the ultimate strength; for Grade C construction 75 per cent is allowable. The following table gives the strand sizes, weights, and ultimate strength of guy wire.

Diam., in.	Approx. weight, lb. per 1,000 ft.	Approx. strength, lb.	Diam., in.	Approx. weight, lb. per 1,000 ft.	Approx. strength, lb.
3/4	1,200	16,700	3/8	273	4,250
5/8	813	11,600	5/16	205	3,200
9/16	671	9,600	9/32	164	2,570
1/2	517	7,400	1/4	121	1,900
7/16	399	5,700			

POLE-LINE CONSTRUCTION

60. A single crossarm assembly for a two-wire, single-phase circuit is shown in Fig. 47. Additional insulators for three- or four-wire lines may be added to the arm 14½ in. closer to the pole from the insulators shown. This type of arm is used for normal spans and loads where there is a straight line with no obstructions.

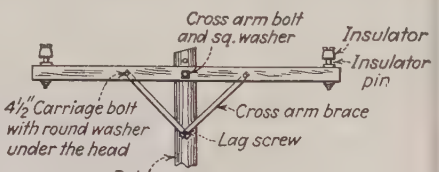


FIG. 47.—Single crossarm assembly.

61. Double arms are used wherever the stress on the arms is unusually severe or where every precaution is necessary to ensure safety. Double arms are often used on the poles at each side of a street intersection, at each side of railroad crossings, and at corners or other

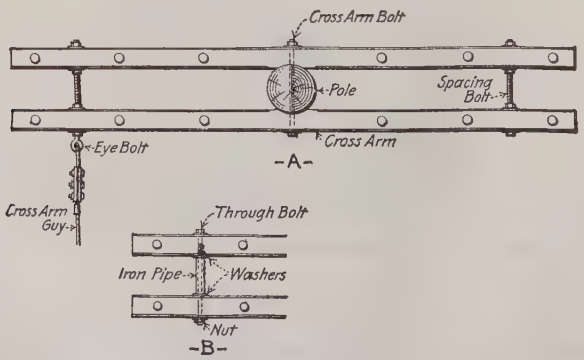


FIG. 48.—Method of arranging double arms.

points where the direction of a line changes. Figures 48, 51, 52, 70, 86, 87, 89 and 90 show examples of double-armed poles. The two crossarms can be separated by wooden spacing blocks (Fig. 51), by spacing bolts or double-arming bolts (Fig. 48*A*), or by spacing nipples (Fig. 48*B*).

The spacing blocks can be sawed from a crossarm. An $1\frac{1}{16}$-in. hole bored through the block and crossarm accommodates a $\frac{5}{8}$-in. bolt. A washer is used under bolthead and nut. Spacing bolts or double-arming bolts can be used instead of spacing blocks (Fig. 48*A*); the bolts are threaded for most of their length. A galvanized-iron pipe nipple can also (Fig. 48*B*) be used to separate the crossarms. A $\frac{3}{4}$-in. spacing bolt probably provides the preferable and most economical method; spacing blocks rot readily, and the bolts through them corrode rapidly. Where an arm guy is to be attached to the crossarm, a double-arming eyebolt can be used as shown. Single-armed poles are now often used, particularly on junction poles, as shown in the accompanying illustrations, in locations where double arms were formerly thought necessary. The single arms are preferable in that they allow greater climbing space for linemen.

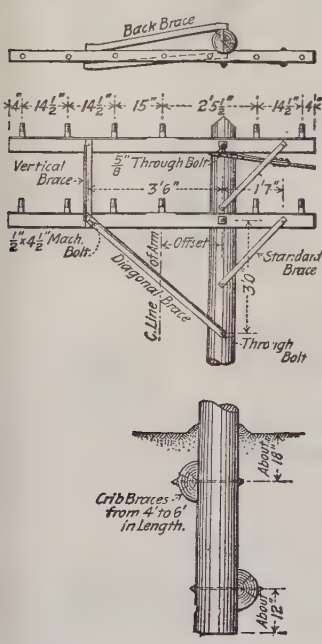


Fig. 49.—A side-arm pole.

62. Alley arms (Figs. 49 and 50) are used in alleys and other locations where it is necessary to clear obstructions by offsetting the crossarm toward one side

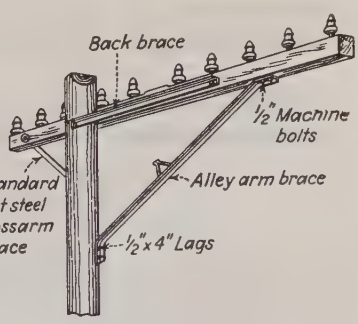


Fig. 50.—Bracing for alley arms. (*Hubbard & Co.*)

of the pole. The crossarms will be special arms, but standard material can generally be used for the rest of the construction. Types of standard braces for side-arm construction are discussed in Sec. **40.** Side guys or crib braces (see Fig. 49) are used where the line wires are heavy, to counteract the tendency of the pole to tip.

63. Reverse or buck arms are used at corners (see Figs. 51, 52, 86, and 87). In placing buck arms, ample room must be provided through which a lineman can reach the top of the pole. A 20-in. square space is the minimum. Crossarm braces on buck-arm poles should be attached to

the arms at a point 23½ in. from the center of arm instead of at 19 in., the standard distance for ordinary framing. The ⅜-in. holes for the

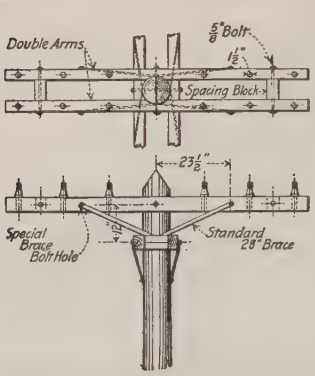


FIG. 51.—A buck-armed pole, double arms.

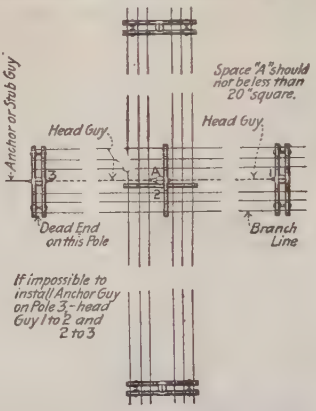


FIG. 52.—Junction pole without double arms.

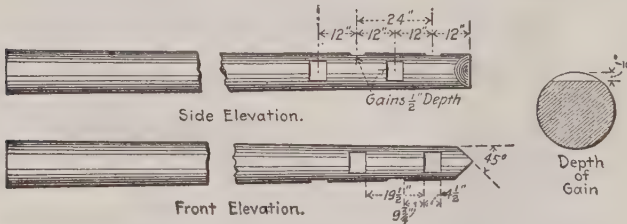


FIG. 53-I.—Gains in pole.

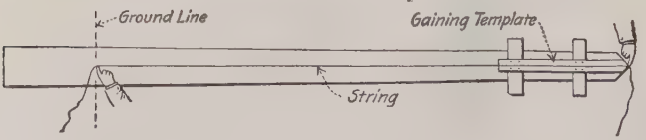


FIG. 53-II.—Use of gaining template.

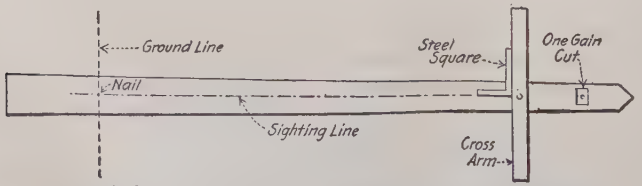
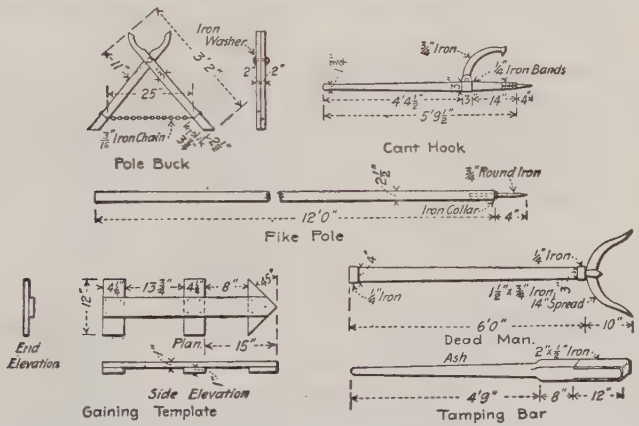


FIG. 53-III.—Locating gain with steel square and crossarm.

brace (carriage) bolts must be specially bored, at the above spacing, in buck arms. The 23-in. spacing is correct for 28-in. braces.

64. A gain is a flat bearing surface on the pole at the point of attachment of the crossarm so that the crossarm will be rigid. The gain is usually formed by cutting a notch in the side of the pole, as shown in Fig. 53. The gaining template of Fig. 54 is convenient in laying out the gains. The gain should be exactly the width of the crossarm, ensuring a snug fit. In good work, gains should always be spaced on 24-in. centers and should be ½ in. deep. Nothing is accomplished by making them deeper. In using the gaining template (Fig. 53, II) the point of the "roof" of the template is placed exactly over the point of the roof of the pole and the template is shifted until its center line (which should be



Note.—The tool illustrated above as a *Cant-Hook* is properly termed a *Peavie.* A peavie has a spike in the end of its handle, while a cant-hook has no spike.

FIG. 54.—Some line-construction tools.

marked thereon) lies exactly under a cord stretched from the roof point to the center of the pole at the ground line. Then the positions of the crossarm gains are indicated by knife scratches made along the sides of the crosspieces on the template.

Where a gaining template is not available, a crossarm (Fig. 53, III) can be laid on the pole with a steel square held against its lower face, the outer edge of the short limb of the square lying at the center of the pole and the center of the crossarm. Rotate the crossarm in a horizontal plane until, by sighting, it is evident that the edge of the square coincides with an imaginary center line to a nail in the center of the butt at the ground line. Indicate the gain location by knife scratches along the crossarm sides.

65. Metal gains (Fig. 55, I) may be used in attaching the crossarm to the pole instead of notching the pole. By spacing the crossarm about ½ in. away from the pole they allow for complete drainage of water from the joint and prevent rotting of the pole and crossarm. Also, at

double-arming locations, the use of metal gains spaces the crossarms about 2 in. farther apart, which allows more room between the pin insulators on the two arms and more room for tie wires, an important factor on the higher voltage lines. Metal gains are a great convenience

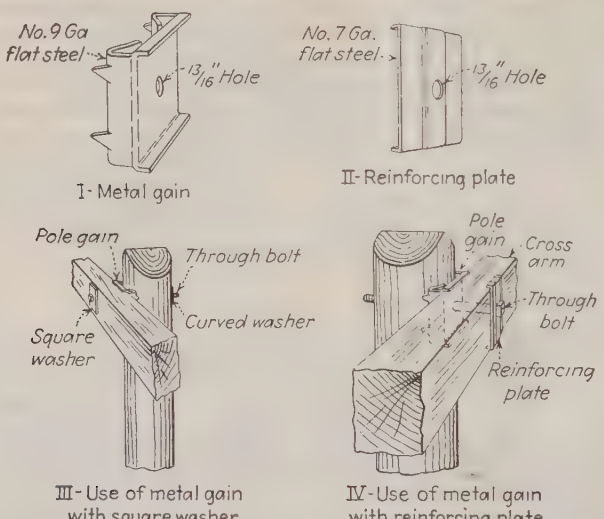


FIG. 55.—Metal gains. (*Hubbard & Co.*)

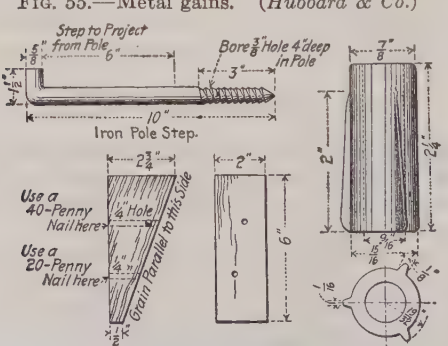


FIG. 56-I.—Pole steps and socket.

when installing an additional crossarm to an existing pole which did not have the gain cut in it. In using metal gains a square washer may be used under the head of the through bolt (Fig. 55, III). A better construction is to use a reinforcing plate (Fig. 55, II) located on the outside of the crossarm (Fig. 55, IV). This makes for a more rigid construction

and helps to prevent checking and splitting of the crossarm at the attachment point.

66. Pole steps (Fig. 56, I) can be located on the pole as shown in Fig. 56, II. A $\frac{3}{8}$-in. hole 4 in. deep is bored for the iron step. It is driven into the hole until it projects 6 in. from the pole and is then turned with a wrench until the hook end is vertical. The wooden step is held to the pole with one 40-penny and one 20-penny nail or with cut spikes. Often the wooden steps are omitted. The lowest iron step should be at least 7 ft. from the ground. Pole steps should extend from the pole parallel with the center line of the street on which the pole is set.

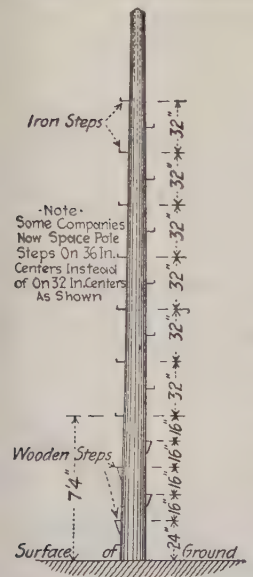


FIG. 56-II.—Location of pole steps on pole.

Pole-step sockets (Fig. 56, I) are sometimes substituted for the wooden steps. The sockets drive into a $\frac{7}{8}$-in. hole. To climb the pole a lineman can temporarily insert bolts or similar pieces of metal into the sockets.

67. Secondary racks are mounted on the sides of poles or buildings to carry low-voltage mains, usually of 440 volts or less, to locations where building services are tapped off. Figure 57, II, illustrates the rack used as a dead end with a head guy to take the tension of the wires. The building service in this case is tapped with open wires. The higher voltage wires are shown mounted on the crossarm at the top of the pole. Figure 57, I, shows two secondary lines crossing; Fig. 57, III, shows a corner pole; Fig. 57, IV, shows the secondary wires supported on the side of the pole with an open-wire service tap; Fig. 57, V, shows a similar construction with taps to a service cable. Mounting of racks on brackets on the side of a building is shown in Fig. 57, VI, with the service wires entering a service cap and conduit.

68. Distribution transformers reduce the primary line voltage to a low secondary voltage suitable for customers' use. They are mounted on the side of poles or on a platform between poles. Figure 58, I, shows such a transformer mounted on special crossarms in the space between the high-voltage wires at the top of the pole and the low-voltage wires on the secondary rack. Taps connect the primary of the transformer, through fuses mounted on the extra crossarm, to the high-voltage wires. The secondary of the transformer is connected directly to the secondary wires at the secondary rack. Attention should be given to making these connections in a neat manner, using right-angle bends and running the several wires of a circuit parallel to each other. Wherever there is danger

of a wire touching another wire or a cross-arm or brace or coming too close to a pole, wire-holder insulators (Fig. 34) or pin insulators should be installed on the sides of crossarms to keep the connecting wires in their proper position. Figure 58, II shows a similar arrangement where the secondary wires are closer to the primary wires and the transformer must be mounted below the secondary wires. The insulators on the transformer crossarm keep the primary taps at a safe distance away from the secondary wires. A compact installation is shown in Fig. 58, III. Such

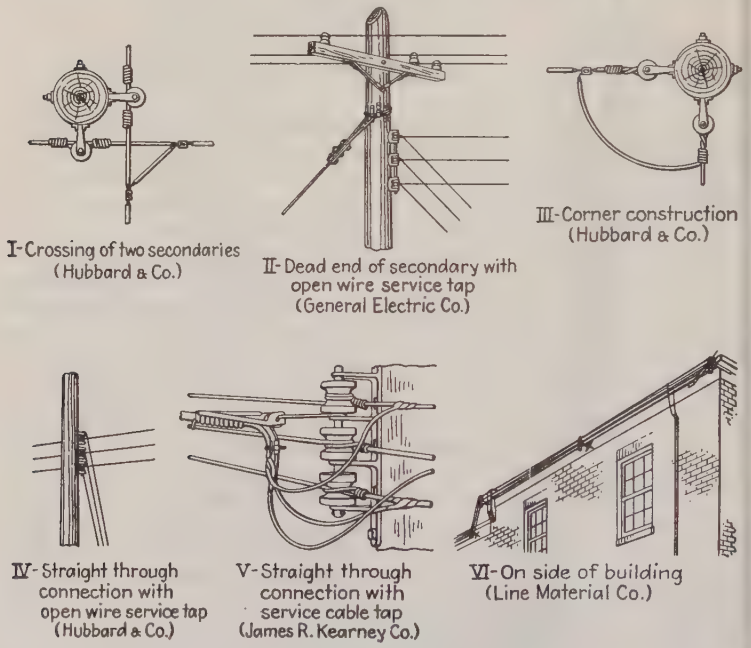
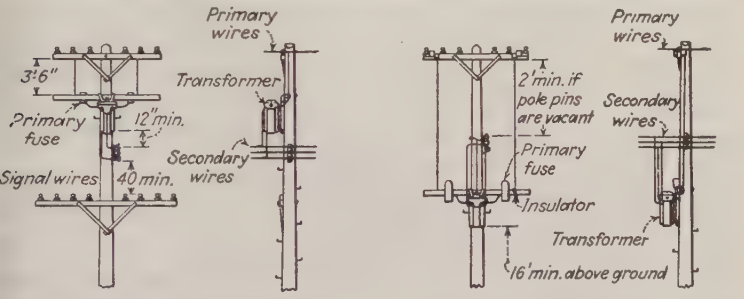


FIG. 57.—Ways of using secondary racks.

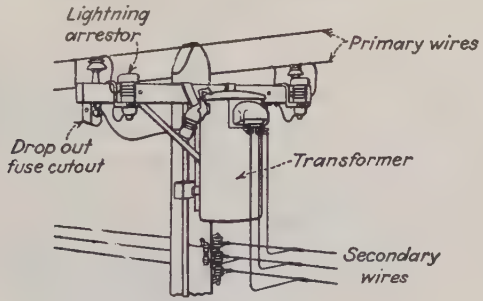
an arrangement is quite satisfactory when there are only two primary wires spaced sufficiently far apart to give plenty of climbing and working space. A three-phase bank consisting of three single-phase transformers can be mounted on a platform supported from two poles located fairly close together. This is common practice for supplying an industrial plant. For three-phase distribution along city streets the three transformers may be mounted singly on adjacent poles, each one similar to Fig. 58, I. This practice is preferable where the transformer platform would be too conspicuous and unsightly. Additional details for the mounting of transformers are given in Div. 5.

69. In locating circuits on poles the through wires or trunk lines should be carried on the upper crossarms, and the local wires, those which are tapped frequently, should be carried on the lower crossarms. The two or three wires of a circuit should always be carried on adjacent pins. This is of particular importance with a-c circuits as the inductance, and consequently the inductive voltage drop, is increased as the distance



I - Single phase transformer mounted in space between primary wires and secondary rack. (Line Material Co.)

II - Single phase transformer mounted below secondary rack. (Line Material Co.)



III - Single phase transformer mounted on same cross arm with primary supply wires. (General Electric Co.)

FIG. 58.—Mounting and wiring of distribution transformers.

between the wires of a circuit is increased. Wires of a circuit should always take the same pin positions on all poles to facilitate trouble hunting. Series circuits which do not operate during the daytime may often be carried on the pole pins of a crossarm. High-tension multiple circuits that are "hot" continuously are well placed at the ends of the arms out of the way of linemen. The neutral wire should always be in the center of a three-wire circuit. Figure 59 shows one good arrangement on a two, four-pin-arm pole.

70. Joint use of poles for circuits of different power companies or for circuits of a power company and a telephone or a telegraph company is frequently advantageous where the lines run along the same route (Fig. 60). In the rules for location of conductors and clearances, the power-company circuits are frequently called simply supply wires; the telephone and telegraph company circuits are called communication wires. The National Electrical Safety Code provides that when supply circuits of different companies are located on the same pole, the higher voltage line should be carried at the higher level except that the lines of each company may be grouped together and always carried in the same relative position. For each company the lines of higher voltage should be located in the higher position. Whenever a lower voltage line is carried above a higher voltage one, it must be on the opposite side of the pole. A

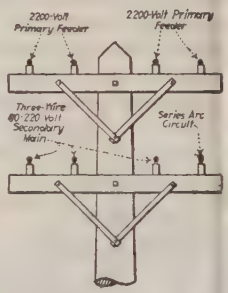


FIG. 59.—Location of circuits on a two-arm pole.

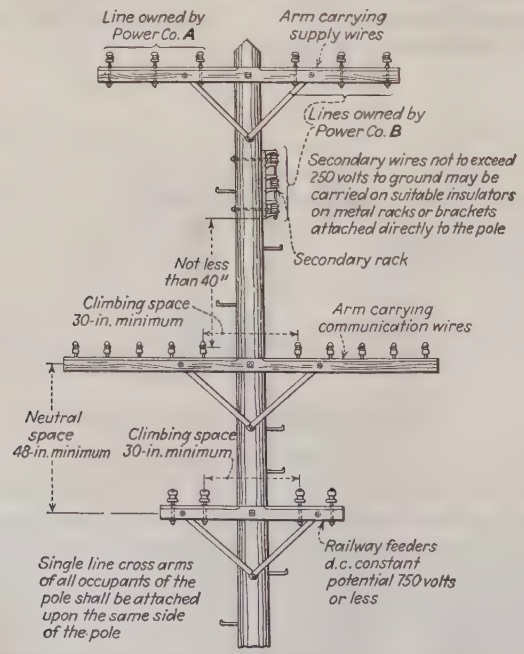


FIG. 60.—Construction of jointly used wood-pole lines carrying supply circuits and signal circuits, showing arrangement of attachments and clearances. (*Hubbard & Co.*)

vertical clearance of at least 4 ft. must be maintained between wires of different power companies, and a clearance of 6 ft. must be used if required by the rules of Sec. **73.** Supply wires must be carried above communication wires except that minor extensions may be made to existing systems which were installed with the communication wires above. Trolley feeder wires may be carried at the approximate level of the trolley wires irrespective of whether that location brings them above or below the communication wires. The climbing space (for a workman to climb the pole) between the wires nearest the pole on the lower level lines must be at least as great as given in the following table:

71. Minimum Climbing Space between Wires Next to the Pole

Conductor and Voltage of the Wires Adjacent to the Climbing Space	Minimum Climbing Space, In.
1. Poles used solely for communication wires:	
a. 0–150 volts	No requirement
b. Over 150 volts	24
2. Poles used solely for supply conductors:	
a. 0–300 volts	24
b. 300–7,500 volts	30
c. 7,500–15,000 volts	36
d. 15,000–50,000 volts	60–84
3. Poles used jointly for supply and communication conductors..	
Power conductors above communication conductors	Same as 2
Power conductors below communication conductors:	
a. 0–7,500 volts	30
b. 7,500–15,000 volts	36
c. 15,000–50,000 volts	60–84
Communication conductors above power conductors	Same as 1
Communication conductors below power conductors	30

72. Power-supply conductors owned by the same company must be separated at least by the distance given below:

Voltage between conductors	Minimum horizontal spacing	Minimum vertical spacing
Up to 7,500	1 ft.	2 ft.
7,500–50,000	1 ft. increased by[a] 0.4 in. for each 1,000 volts above 7,500 volts	4 ft.
Above 50,000	1 ft. increased by[a] 0.4 in. for each 1,000 volts above 7,500 volts	4 ft. increased by 0.4 in. for each 1,000 volts above 50,000 volts

[a] For the higher voltage, longer span lines, the following formulas apply if they give a separation greater than that given in the table.

For wires smaller than No. 2:

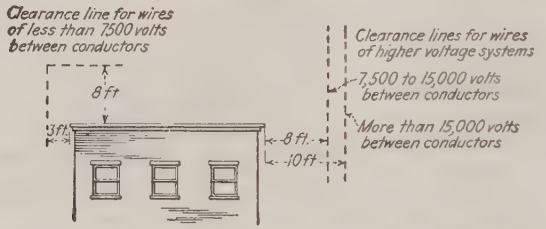
$$\text{Separation} = 0.3E + 7\sqrt{\frac{S}{3} - 8}$$

For wires No. 2 and larger:

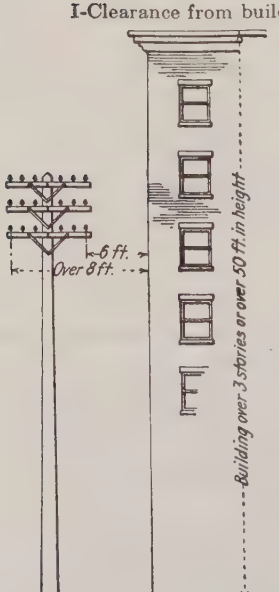
$$\text{Separation} = 0.3E + 8\sqrt{\frac{S}{12}}$$

where the separation is in inches, E = line voltage in kilovolts, and S = greatest sag of conductor at 60°F. in inches.

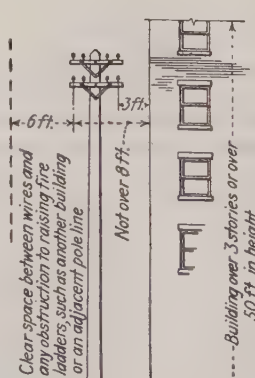
73. The minimum distances between conductors at supports are specified by the National Electrical Safety Code. Communication conductors must be spaced 6 in. apart horizontally. They must be located not less than 4 ft. vertically from supply wires up to 7,500 volts and not



I-Clearance from building according to line voltage.



II-Clearance from high building when long cross-arms are used.



III-Clearance from high building when short crossarms are used.

FIG. 61.—Clearances of wires from the outside of buildings. (*Abbott, National Electrical Code Handbook, 4th Ed.*)

less than 6 ft. vertically from supply wires of circuits of 7,500 to 50,000 volts. Minimum required clearances for power-supply wires are given in Sec. **72.** Conductors on secondary racks may have a vertical separation of only 4 in. where the voltage is not more than 750 volts and the

spans are not over 150 ft. long. Either 6 or 8 in. separation is more common for rack construction, however. There are some exceptions to these rules for special construction, and anyone desiring to use somewhat lower clearances is advised to consult the National Electrical Safety Code.

74. Clearances of wires above ground are specified by the National Electrical Code and by the National Electrical Safety Code as follows.

Type of ground surface	Voltage	Minimum clearance of wires above ground, ft.
Residential property and spaces accessible only to pedestrians	Not over 150 volts to ground	10
	150–300 volts to ground	12
	300–15,000	15
	15,000–50,000	17
Driveways to residence garages	0– 750	10
	750–15,000	20
	15,000–50,000	22
Automobile parking lots and similar commercial areas	.....	12
Roads in rural districts	0– 750	12 (if located beyond reach of vehicle)
	.....	15 (otherwise)
	750–15,000	18
	15,000–50,000	20
Alleys, driveways, and streets in urban districts	0– 600	18
	600–15,000	20
	15,000–50,000	22
Railroad tracks where men are not permitted on top of cars	0– 750	18
	750–15,000	20
	15,000–50,000	22
Railroad tracks where men are permitted on top of cars	0– 750	27
	750–15,000	28
	15,000–50,000	30

For voltages above 50,000 volts the clearance must be increased by ½ in. for each 1,000 volts increase above 50,000 volts.

74A. Clearances of wires from buildings are specified by the National Electrical Code (Fig. 61). Wires passing over buildings must be at least ft. above the roof, except that service drops operating at 300 volts or ss may be not less than 3 ft. from the highest point of roofs that cannot e readily walked upon. Open conductors must be kept at least 3 ft. orizontally from windows, doors, porches, fire escapes, or similar cations.

The horizontal clearance from buildings is given in the following table:

Line Voltage	Horizontal Clearance from Buildings, Ft.
0–7,500	3
7,500–15,000	8
Over 15,000	10

If buildings are over three stories or over 50 ft. in height, a clear space at least 6 ft. wide for raising of fire ladders must be left either adjacent to the building or beginning not more than 8 ft. from the building. The clearance requirements of wires from the outside of buildings are illustrated in Fig. 61. Service drops or final spans of feeders to buildings they serve or from which they are fed must necessarily approach the building more closely than indicated, but they shall be kept away from windows, doors, porches, fire escapes, or similar locations and shall be run to the building in such a way as to avoid any hazard.

74B. Wiring on Buildings.—Outside wiring attached to a building or run between buildings may be installed as open conductors on insulating supports, as multiple-conductor cable approved for the purpose, in rigid metal conduit, or in electrical metallic tubing; except that, for circuits of more than 600 volts run on the exterior building walls, conductors may be installed in electrical metallic tubing only for sign and outline lighting as provided in the Code. Other conductors of more than 600 volts shall be installed in rigid metal conduit or cable approved for the purpose.

Conductor Insulation.—Open conductors supported on insulators shall be of the rubber-covered type, thermoplastic type, or weatherproof (Type WP), where within 10 ft. of any building or structure. Conductors in cables or raceways shall be of the rubber-covered type or thermoplastic. Conductors for festoon lighting shall be of the rubber-covered or thermoplastic type.

Size of Conductors.—The size of conductor shall conform to the following:

1. **Carrying Capacity.**—Conductors shall conform to the allowable current-carrying capacities of Tables 18 and 18*A* of Div. 11.

2. **Overhead Spans.**—Overhead conductors shall not be smaller than No. 10 for spans up to 50 ft. in length, and not smaller than No. 8 for longer spans.

3. **Festoon Lighting.**—Overhead conductors for festoon lighting shall not be smaller than No. 12 unless supported by messenger wires.

4. **Over 600 Volts.**—Overhead conductors of over 600 volts shall not be smaller than No. 6 unless in cable. Conductors in cable shall not be smaller than No. 8.

Supports.—Open conductors shall be supported as follows:

1. **Open Conductors.**—Open conductors shall be supported on glass or porcelain knobs, racks, brackets, or strain insulators, approved for the purpose.

2. **Festoons.**—In spans exceeding 40 ft. the conductors shall be supported by a messenger wire supported by approved strain insulators. Conductors or messenger wires shall not be attached to any fire escape, downspout, or plumbing equipment.

Spacings.—Conductors shall conform to the following spacings:

1. **Open Conductors Not Exposed to Weather.**—Open conductors not exposed to the weather shall be supported at intervals not exceeding 4½ ft. and shall be separated not less than 2½ in. from each other and 1 in. from the surface wired over.

2. **Open Conductors Exposed to the Weather.**—Except in open spans, conductors exposed to the weather shall be supported at intervals not exceeding 9 ft., separating the conductors at least 6 in. from each other and at least 2 in. from the surface wired over; provided that supports may be placed at intervals not exceeding 15 ft. if conductors are separated at least 12 in. from each other. For 300 volts or less, conductors may have a separation of not less than 3 in. if supports are placed at intervals not exceeding 4½ ft. and conductors are not less than 2 in. from the surface wired over. In open spans, conductors shall be separated at least 12 in. from each other.

3. **Over 600 Volts.**—Except in open spans, open conductors on circuits of over 600 volts shall be separated not less than 8 in. from each other and not less than 2 in. from the surface wired over for voltages of 2,500 volts or less and 3 in. for voltages exceeding 2,500 volts. In open spans, conductors shall be separated at least 12 in. from each other.

4. **Separation from Other Conductors.**—Open conductors shall be separated from open conductors of other circuits or systems by not less than 4 in.

Protection on Buildings or Structures.—Where open conductors are subject to mechanical disturbance, or are readily accessible, they shall be protected by rigid metal conduit, electrical metallic tubing, shall be of multiple-conductor cable approved for the purpose, or shall have equivalent protection.

Protection on Poles.—Conductors on a pole shall be protected from mechanical injury to a point at least 8 ft. from the ground.

Multiple-conductor Cables.—Multiple cables of Type SD shall have insulating supports at intervals not exceeding 15 ft. and maintaining a distance of not less than 2 in. from the surface wired over and shall be protected where within 8 ft. from the ground or where subject to mechanical injury. Multiple-conductor cables of Type SE or ASE mounted in contact with the building shall be supported at intervals not exceeding 4½ ft.

Raceways.—Conduit and electrical metallic tubing on exterior of building shall be made raintight and suitably drained.

75. Tying In Wires.—Normally the wires should rest in the insulator grooves as shown in Fig. 62*A*, but where there is a side stress the wires should be so arranged that the pull comes against the insulators rather than away from them (Fig. 62*B*). A single tie for the smaller wires is shown in Fig. 63, I, and a back tie for the larger wires is shown at II. The

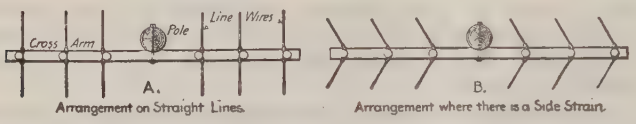
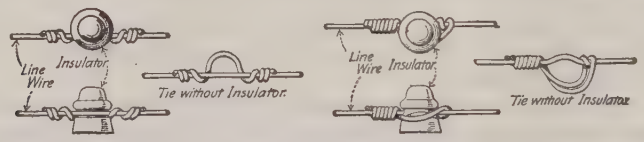


FIG. 62.—Positions of wires in insulator grooves.

single tie wire is about 12 in. long, and the back tie about 18 in. long. The back tie is made as follows: Bend the tie around the insulator under the line wire, with 4 in. on one side of the insulator and the balance on the other side. Wrap the short end three times around the line wire, leaving



I-Single Tie II-Back Tie

FIG. 63.—Methods of tying. (Preferably, the tie wires should not be cut off flush as shown above. Instead their ends should be permitted to stick out or to lie along the line wires. This is to facilitate their removal.)

a space equal to the diameter of the tie wire between successive wraps. Now wrap the long end of the tie wire three times completely around the line wire, then back around the insulator and wrap it in the spaces left between the wraps of the other end of the tie wire. Refer to Fig. 63 for instructions regarding cutting of tie wires.

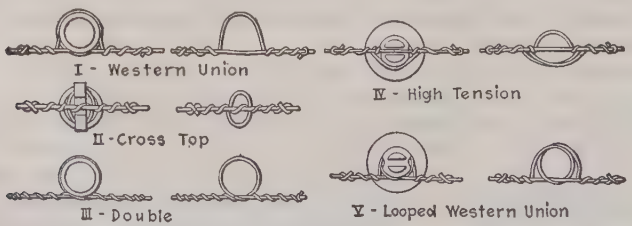


FIG. 64.—Ties of the different types used in ordinary distribution systems. (See Table 77.)

76. Different types of insulator ties which have been standardized by a western power company are shown in Fig. 64 and Table 77. The company uses medium-hard-drawn line wire. Although good ties may be made with a medium-hard-drawn, weatherproof tie on a weatherproof

line wire, medium-hard-drawn ties are not desirable on bare wires, as the bending radius is too small for these stiff wires. Hence, annealed bare-wire ties are used for bare line wires. Annealed ties may be cut from purchased annealed copper. Do not use a tie wire twice, as, after once being bent and strained, it will be brittle. The following table of sizes has been recommended for ordinary stresses. For very heavy stresses heavier tie wires should be used.

Line wire, size	Tie wire, size	Kind of tie	Line wire, size	Tie wire, size	Kind of tie
6	6	Single	1	4	Back
4	6	Single	2/0 and larger	2	Back
2	4	Single			

Tie wires should usually have the same kind of insulation as the line wire which it confines. The National Electrical Code requires this on indoor work, and it is also good practice on outdoor work.

77. Table Showing Types of Insulator Ties for Different Services

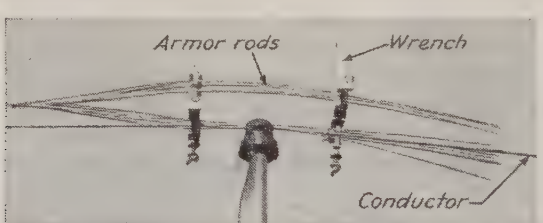
Size of line wire, gage or in.	Insulator	Top or side	Tie material	Tie length, in.	Type of tie	Fig. 64
			COPPER			
6 or 4 W P	D.G.D.P.	Side	6 W P m.h.d.	25	Western Union	I
2 W P	D.G.D.P.	Side	4 W P m.h.d.	27	Western Union	I
1/0 to 4/0 W P	Cable	Top	4 W P m.h.d.	36	Cross-top	II
1/0 to 4/0 W P	Cable	Side	4 W P m.h.d.	30	Western Union	I
6 or 4 bare	D.G.D.P.	Side	6 bare ann.	27	Double	III
6 or 4 bare	11 kv.	Top	6 bare ann.	40	High-tension	IV
2 bare	11 kv.	Top	4 bare ann.	40	High-tension	IV
1/0 to 4/0 bare	11 kv.	Top	2 bare ann.	44	High-tension	IV
6 to 4 bare	11 kv.	Side	6 bare ann.	40	Looped W.U.	V
2 bare	11 kv.	Side	4 bare ann.	40	Looped W.U.	V
1/0 to 4/0 bare	11 kv.	Side	2 bare ann.	48	Looped W.U.	V
			STEEL			
¼ and 5/16	D.G.D.P.	Side	1 strand, 5/16 in.	27	Double	III
¼ and 5/16	11 kv.	Top	1 strand, 5/16 in.	44	High-tension	IV
⅜	11 kv.	Top	1 strand, ⅜ in.	44	High-tension	IV
¼ and 5/16	11 kv.	Side	1 strand, 5/16 in.	48	Looped W.U.	V
⅜	11 kv.	Side	1 strand, ⅜ in.	48	Looped W.U.	V

78. The bare tie wires for uninsulated line wires should always be of the same metal as the line wire. If dissimilar metals are employed,

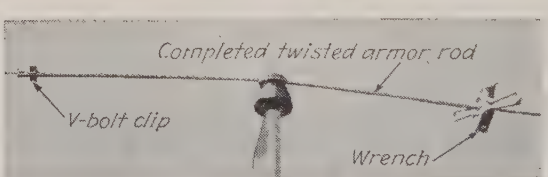
electrolytic corrosion and a consequent weakening and possible breakage of the line wire at the tying point may result. That is, bare copper tie wires should always be used on bare copper line wires, and galvanized-iron tie wires on galvanized-iron line wires.

79. In making up line-wire ties, the tie wire should not be drawn too tightly around the line wire. The tendency of the beginner is to do this, with the result that the line wire is weakened and will probably sever when it is first subjected to an unusual stress such as that which is likely to occur when a low temperature prevails.

80. In making ties on ACSR wire (see Div. 2) the conductor must first be reinforced by wrapping with armor rods twisted around the conductor with the aid of two special wrenches.



I-Inital step. Wrenches ready to be closed around conductor leaving one end of rods taped.



II-Final step. Wrench in final position ready for application of second V-bolt clip.

FIG. 65.—Installing armor rods at insulator support for ACSR wire. (*Aluminum Company of America.*)

Armor rods are shipped in sets (bundles) with the ends taped and with the center marked. Remove the tape from one end of the set and thread the rods through the two armor-rod wrenches, making sure that both the wrenches open between the *same two rods*. Leaving the set taped at one end keeps the rods from sliding while the assembly is being sent aloft and keeps ends even while making the first twist.

Center the armor rods on the conductor over the point of support. Open the wrenches and then close them with the rods around the conductor, (Fig. 65, I). Shift the wrenches on the rods to such a position that the middle third of the armor rods will be twisted with the first turn of the wrenches. Rotate the wrenches counterclockwise to make the

lay of the rods in the *same* direction as the lay of the cable. Twist the rods to give them a permanent set, so that the wrenches do not tend to spring back. After twisting the middle third, cut the remaining tape and slide the wrenches half way to the ends. Turn the wrenches and twist the rods as before. Finally slide the wrenches as close as possible to the ends, twisting this last section the same as for previous settings.

The rods should be twisted snugly with a smooth lay. If twisted too tightly, there is a tendency to force one or more rods out of the layer, and the rods will stand away from the cable so that the assembly can be

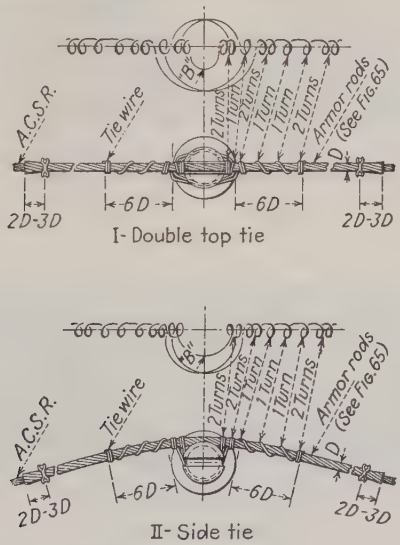


Fig. 66.—Ties for ACSR wire. (*Aluminum Company of America.*)

slipped along the conductor before the armor-rod clips are applied. There is a "stopping point," which can be felt after a little practice.

The armor-rod (V-bolt) clips should be applied about 1½ in. from the ends of the assembly, which can best be accomplished by installing and tightening the V volts while the armor-rod wrenches are still in their final twisting position (Fig. 65, II). This procedure leaves the ends of the rods slightly flared away from the conductor. If the wrenches are removed prior to tightening the armor-rod clips, the ends of the rods may have to be flared as a separate operation.

After installation of the armor rods the ties are made as shown in Fig. 66. Figure 66, I, shows a top tie with the conductor on top of the insulator, and Fig. 66, II, shows the conductor tied on the side groove of the insulator. Above each view is shown a sketch of the manner in which the tie wire is wrapped and looped.

81. For ties on copperweld wire use annealed copper tie wires of the size given in the following table as recommended by the Copperweld Steel Co.:

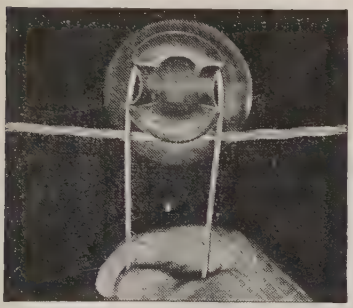
Size of conductor, A.w.g.	Size of tie wire, A.w.g.	Length of tie wire,[a] in.	
		Top tie	Side tie
Bare, Solid Wire Conductors			
10	10	38	44
9	9	40	46
8	8	42	48
7	8	42	48
6	6 or 8	46	52
5	6 or 8	50	56
4	6 or 8	50	56
Three-wire Stranded Conductors			
3 No. 12	8	44	50
2 No. 11	8	44	50
3 No. 10	8	44	50
3 No. 9	6	48	54
3 No. 8	6	50	56
3 No. 7	6	52	58
3 No. 6	6	54	60
Type A Copperweld Copper Conductors			
8A	8	44	50
7A	8	44	50
6A	8	46	52
5A	6	50	56
4A	6	52	58
3A	6	54	60
2A	6	56	62

[a] Includes 4 in. additional length on each end for convenience in applying tie.

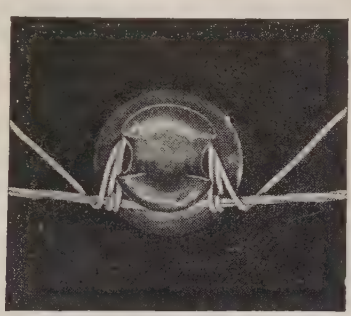
For top ties on copperweld wire, the type shown in Fig. 64, IV, is recommended. For side ties, the one shown in Fig. 67 with three loops around the insulator is used.

82. For dead-ending of line wires at the end of a run or at corners, various types of construction may be used. For low-voltage, secondary rack construction a rack may be located on the front of the pole, and the tension taken by bolts through the pole (Fig. 68, I). The wires are looped around the rack insulators, and the end of the wire is wrapped

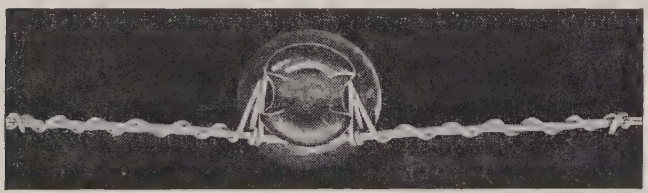
around the line conductor. Other low-voltage dead ends may be made up as in Fig. 69. Pin insulators may be used for dead ends where the line tension is not too great. Figure 68, II shows a dead end of service



I-Bend tie wire around insulator above conductor to form a "U." Both legs of the tie wire should be of equal length after binding.



II-Holding tie wire tightly against insulator, throw two tight close wraps around conductor on each side of the insulator—then cross legs of tie wire around insulator.



III-Finish with six tight 45 deg. spiral wraps on each side of the insulator. Bend back ends and cut off.

FIG. 67.—Side tie for copperweld wire. (*Copperweld Steel Co.*)

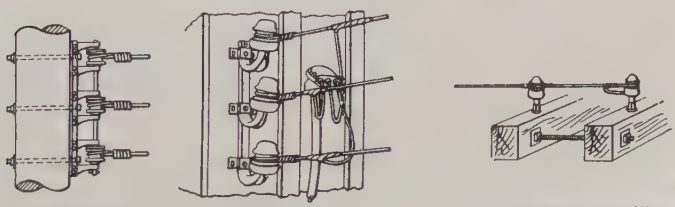


FIG. 68.—Low-voltage dead ends. (*Hubbard & Co.*)

wires with pin insulators on the side of a building. The wire is looped around the side groove in the insulator similar to the way it is secured on the rack insulator. Dead ends may be made on pin insulators on double crossarms as shown in Fig. 68, III. This construction is recom-

mended only for the smaller sizes of wires with light pulls, as the pins may break or bend with heavy loads. For heavier loads a low-voltage dead end on a crossarm may be made by using a strain insulator as shown in Fig. 70, I. For higher voltages one or more suspension insulators with a clamp to grip the conductor, as shown in Fig. 70, II and III, may be used. Instead of the conductor clamp the conductor may be looped around a dead-end thimble (Fig. 71).

83. Where wires are carried through trees so that they would rub against branches, special tree wire (Fig. 72, I) should be used. This wire has a tougher insulation which will resist abrasion from the branches better than weatherproof wire. Where the tree branches are more or less continuous the tree wire should be used exclusively. If there is a span or more of clearing, it will be economical to splice in weatherproof wire to run through the clear space. For especially severe conditions a length of tree-wire molding (Fig. 72, II, III, and IV) should be added to the wire where the wire passes close to heavy limbs or tree trunks. In some cases a tree insulator (Fig. 73) may be screwed to the limb or trunk of the tree. This insulator has a removable pin and roller (Fig. 73, II) so that the wire may be inserted without cutting and the pin replaced. The roller allows the wire to move freely without being cut. Wires should never be attached rigidly to trees because the swaying of the tree might break the wires.

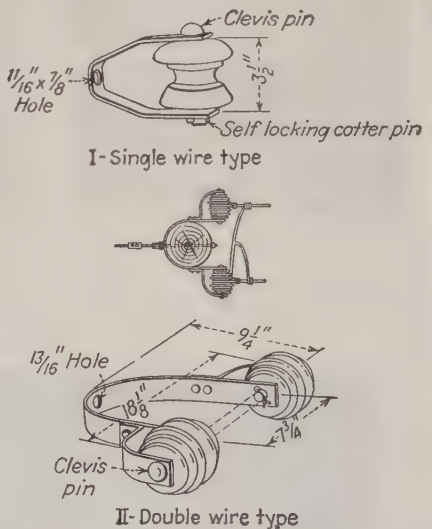
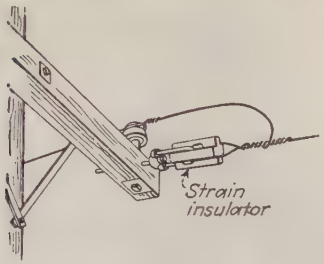


FIG. 69.—Dead-end insulators. (*Line Material Co.*)

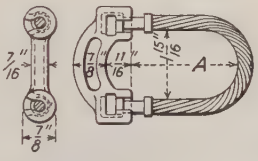
84. Wire and Wire Sizes for Electric Light and Power Lines.—No wire smaller than No. 6 is used in good construction for line wire. No. 8 is sometimes used for services not more than 75 ft. long that do not cross a street. Solid wires are often used for sizes up to and including No. 2/0 and cable (stranded wire) is used for larger conductors. Triple-braid weatherproof is the standard insulation of aerial line wires. Annealed or soft-drawn wire is preferable to hard-drawn for services and secondary distribution lines because it is more readily handled and, in the sizes used, has ample tensile strength. Hard-drawn copper wire or steel-

reinforced aluminum cable is preferable for transmission lines and feeders.

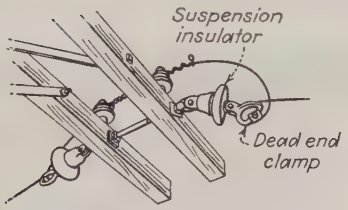
85. Stringing Wire.—There are two methods, the choice depending on local conditions and the size and length of the circuit. By one method



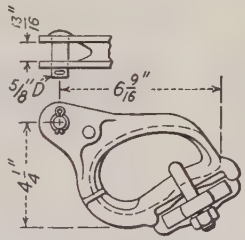
I-Low-voltage dead-end construction, using strain insulator



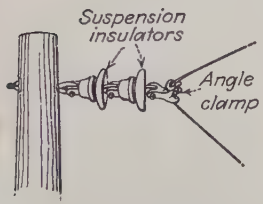
Strain insulator fitting



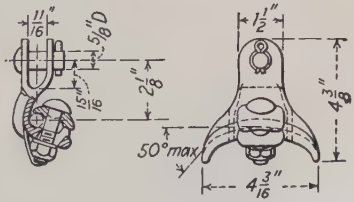
II- 1-5 kv. dead-end construction using suspension insulator and double cross-arms



Dead-end clamp



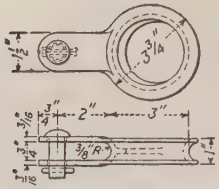
III-5-15 kv. angle construction on pole



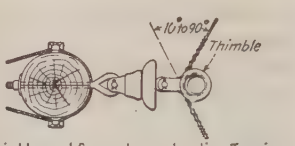
Angle clamp

FIG. 70.—Types of clamps and dead-end construction. (*Ohio Brass Co.*)

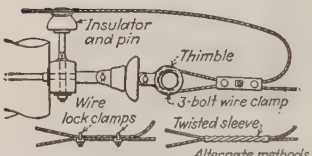
a reel of wire is set at one end of the line, and a rope carried 1,500 or 2,000 ft. over the crossarms and attached to the wire, which is then drawn over the arms. The other way is to place the reel on a cart, and



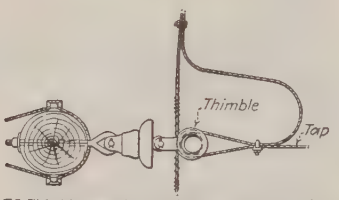
I-Dead-end thimble



III-Thimble used for angle construction. Tie wire is used instead of usual clamping practice

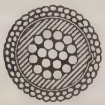


II-Thimble used for dead-ending. With this type of construction the suspension insulator can be replaced without cutting the jumper and making a new dead-end.



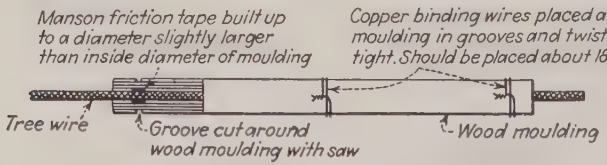
IV-Thimble used for making taps to branch lines The through conductor is tied in at the clevis

FIG. 71.—Dead-end construction with dead-end thimble. (*Ohio Brass Co.*)

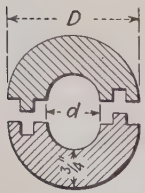


Cross section

I-Detail of insulation on tree wire

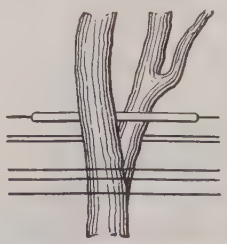


II-Method of installing moulding on tree wire



D and d depend upon size of wire

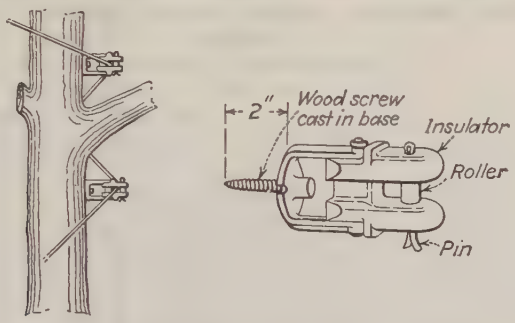
III-Sectional view tree wire moulding



IV-A "Close-up" of tree wire with moulding

FIG. 72.—Tree wiring. (*Okonite Cable Co.*)

after securing the end of the wire to the last pole the cart is started and the wire paid out till the second pole is reached, and then the wire is hoisted up and laid on the arm. Wire should always be paid out from the coil, the coil revolving, so that the wire will not be twisted. Where wire is not received on reels it should be placed on them before paying out.



I-Insulator mounted on tree II-Detail of tree insulator

FIG. 73.—Tree insulator. (*Line Material Co.*)

86. The advantages of an aerial cable installation over an open-wire line are as follows:

1. Better resistance to damage from wind and sleet storms.
2. Better appearance.
3. Less trouble from lightning.
4. Saving of space in congested locations.
5. Low maintenance cost.
6. Low reactance on account of the close spacing of the conductors.

Although the installation cost of aerial cable is higher than for an open-wire line, the total annual cost in regions of severe weather conditions may be lower, in addition to the other advantages.

87. A self-supporting aerial cable consists of an insulated conductor over which is placed a covering of alternate strands of galvanized-steel wire interlocked with special conducting wires. The covering provides a means of supporting the cable, furnishes a ground shield, and provides a low-impedance ground return. This cable is used on 2,300- and 6,600-volt, single-phase grounded circuits where the elimination of tree trimming and tree wire, greater spacing of poles, and the use of less expensive poles will justify the higher initial cost of the cable itself. A self-supporting aerial cable does not require the use of a messenger cable for its support. The cable is supported directly from the poles by means of clamps.

88. An aerial cable installation consists of an insulated cable supported by hangers from a standard steel messenger cable, which in turn is supported from poles. The attachment of the messenger cable to the pole is shown in Fig. 74. The hanger rings supporting the aerial cable are located approximately 20 in. apart. The messenger is dead-ended and guyed as in Fig. 77, II and III.

89. Proper Sag in Annealed Copper Line Wires.—The wires should be pulled up until the sag equals that indicated in Table 90. The values of sag given in these tables are those recommended by the National Electrical Safety Code.

90. Sags for Soft-drawn Covered Copper Wires for Different Span Lengths

(At 30, 60, and 90°F.—wires without load)

Size A.w.g.	Grade of construction	Temperature, deg. F.	Sags, in., for span length of					
			100 ft.	125 ft.	150 ft.	175 ft.	200 ft.	250 ft.
Heavy-loading Districts								
6	C	30	18.0	28.0	44.0			
		60	21.0	32.0	48.0			
		90	24.0	36.0	51.0			
4	A	30	17.5	28.0	45.0			
		60	21.0	32.0	48.0			
		90	24.0	35.0	51.0			
4	B and C	30	14.5	23.0	36.0			
		60	18.0	27.0	40.0			
		90	21.5	31.0	44.0			
2	A	30	14.5	23.0	36.0	49.0		
		60	18.0	27.0	40.0	54.0		
		90	21.5	31.0	44.0	58.0		
2	B and C	30	11.0	17.5	28.0	40.0	55	
		60	15.0	22.0	33.0	45.0	60	
		90	18.5	26.0	38.0	50.0	64	
1	A	30	10.5	17.5	28.0	40.0	55	
		60	15.0	22.0	33.0	45.0	60	
		90	18.5	26.0	37.0	50.0	65	
1	B and C	30	8.5	13.5	21.5	31.0	43	
		60	12.0	18.0	27.0	37.0	48	
		90	15.5	22.5	32.0	42.0	53	
0	All	30	8.5	13.5	20.5	29.0	39	
		60	12.0	18.0	26.0	35.0	45	
		90	15.5	22.5	31.0	39.0	51	
2/0	All	30	8.5	13.5	20.0	28.0	36	
		60	12.0	18.0	25.0	33.0	42	
		90	15.5	22.5	30.0	38.0	48	
4/0	All	30	8.5	13.5	18.5	24.5	30	
		60	12.0	18.0	24.0	30.0	36	
		90	16.0	22.5	29.0	36.0	42	
Medium-loading Districts								
6	C	30	14.5	22.0	36.0			
		60	18.0	27.0	40.0			
		90	21.0	31.0	44.0			
4	All	30	11.0	18.0	28.0	44.0		
		60	15.0	22.0	33.0	48.0		
		90	18.5	26.0	37.0	53.0		

Sags for Soft-drawn Covered Copper Wires for Different Span Lengths (*Continued*)

Size, A.w.g.	Grade of construction	Temperature, deg. F.	Sags, in., for span length of					
			100 ft.	125 ft.	150 ft.	175 ft.	200 ft.	250 ft.
Medium-loading Districts (*Continued*)								
2	All	30	8.5	13.5	22.5	31.0	43	
		60	12.0	18.0	27.0	36.0	48	
		90	15.5	22.0	32.0	41.0	53	
1	All	30	8.5	13.5	20.0	28.0	36	53
		60	12.0	18.0	25.0	33.0	42	60
		90	15.5	22.5	30.0	38.0	48	67
0	All	30	8.5	13.5	19.0	25.0	33	47
		60	12.0	18.0	24.0	31.0	39	54
		90	15.5	22.5	29.0	37.0	45	61
2/0	All	30	8.5	13.5	19.0	24.5	30	41
		60	12.0	18.0	24.0	30.0	36	48
		90	15.5	22.5	29.0	36.0	42	55
4/0	All	30	8.5	13.5	18.5	24.5	30	41
		60	12.0	18.0	24.0	30.0	36	48
		90	16.0	22.5	29.0	36.0	42	55
Light-loading Districts								
6	A	30	14.0	23.0	36.0			
		60	18.0	27.0	40.0			
		90	21.5	31.0	44.0			
6	B and C	30	11.0	17.5	39.0			
		60	15.0	22.0	33.0			
		90	18.5	26.0	37.0			
4	All	30	8.5	13.5	20.0	26.0	36.0	
		60	12.0	18.0	25.0	32.0	42.0	
		90	15.5	22.5	30.0	37.0	47.0	
2	All	30	7.0	11.0	16.0	22.0	30.0	41
		60	10.0	15.0	21.0	27.0	36.0	48
		90	13.5	19.5	26.0	33.0	42.0	55
1	All	30	7.0	11.0	15.0	19.5	24.0	35
		60	10.0	15.0	20.0	25.0	30.0	42
		90	14.0	19.5	25.0	31.0	36.0	49
0	All	30	7.0	11.0	15.5	20.0	24.5	35
		60	10.0	15.0	20.0	25.0	30.0	42
		90	14.0	19.5	25.0	31.0	36.0	49
2/0	All	30	7.0	11.0	15.0	19.5	24.0	35
		60	10.0	15.0	20.0	25.0	30.0	42
		90	14.0	19.5	25.0	31.0	36.0	49
4/0	All	30	7.0	10.5	15.5	19.5	24.0	35
		60	10.0	15.0	20.0	25.0	30.0	42
		90	14.0	19.5	25.0	31.0	36.0	49

POLE-LINE GUYING

91. Guying.—Probably there are not so many guys on pole lines as there should be to ensure continuity of service and minimum maintenance

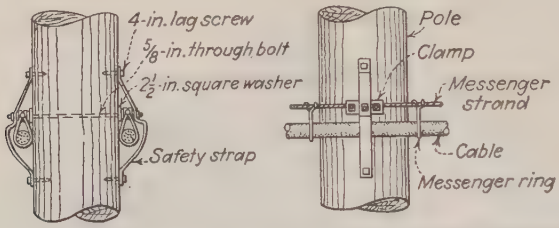


FIG. 74.—Method of supporting aerial cable. (*General Electric Co.*)

expense. Lines should be guyed not for normal conditions but for the most severe conditions that are apt to obtain. The guys should be frequent and heavy enough to sustain the line after the heaviest snowstorm or during the worst possible windstorm. A guy should be used on every pole where the tension of the wires tends to pull the pole from its normal position.

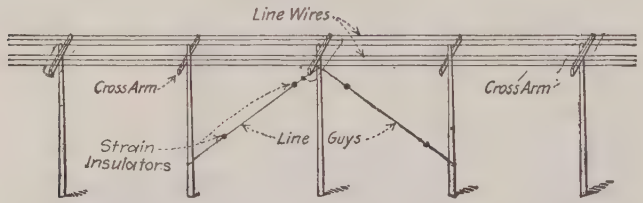


FIG. 75.—Line guys.

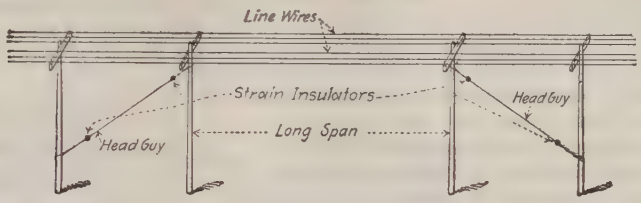
TERMINALS POLES SHOULD ALWAYS BE HEAD-GUYED and on lines carrying three or more crossarms the two poles next to the terminal pole should also be head guyed to distribute the stress.

LINE GUYS are installed on straight pole lines to reinforce them against the excess stresses introduced by storms. It is good practice to install head line guys, as shown in Fig. 75, at about every twentieth pole. This applies only to lines carrying more than one crossarm.

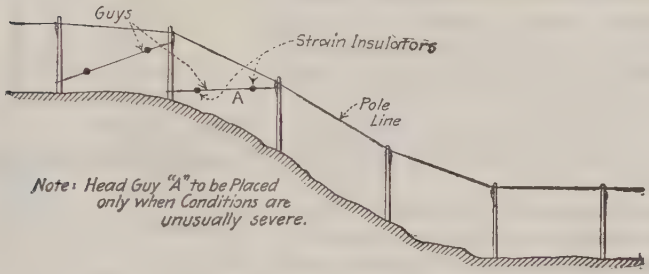
THE INSTALLATION OF ADDITIONAL SIDE GUYS, arranged at right angles to the line, to trees, stubs, or anchors, is recommended. The side guys are attached to the same pole as the head buys.

SIDE GUYS SHOULD BE INSTALLED AT CURVES, the guys taking the direction of radii of the curves. Figure 5 shows a table that gives the number of side guys required for a given line with a given "pull."

The pull is the distance from the pole to a line joining two points in the line 100 ft. on either side of the pole (see Fig. 5).

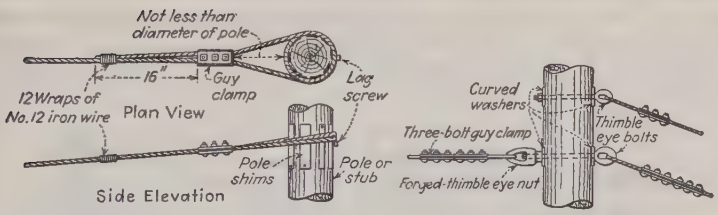


I-Head guys for a long span.



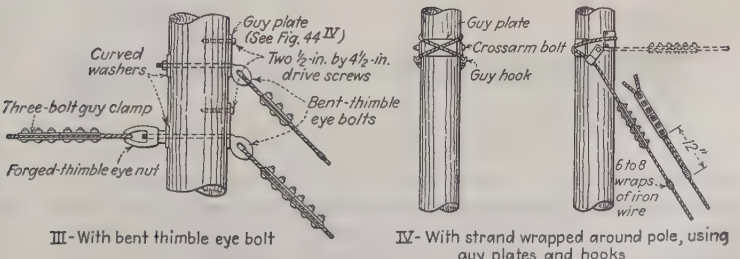
II-Head guys at a steep hill.

FIG. 76.—Head-guy locations.



I-With strand wrapped around pole, using guy shims

II- With straight thimble eye bolt



III- With bent thimble eye bolt

IV- With strand wrapped around pole, using guy plates and hooks

FIG. 77.—Methods of attaching guys to pole. (*General Electric Co.*)

POLES ON EITHER SIDE OF A LONG SPAN should be head-guyed as shown in Fig. 76, I.

LINES ON STEEP HILLS SHOULD BE GUYED as shown in Fig. 76, II with head guys.

POLES AT EACH SIDE OF A RAILROAD CROSSING, IMPORTANT HIGHWAY CROSSING, OR A CROSSING OVER ANOTHER WIRE LINE should be head-guyed away from the crossing as in Fig. 76, I.

GUY WIRES SHOULD BE KEPT MORE THAN 8 FT. FROM THE GROUND where possible to prevent persons from making accidental contact with them. A clearance of at least 3 ft. should be maintained between guys and electric wires, otherwise changes in temperature may cause the wires to come in contact.

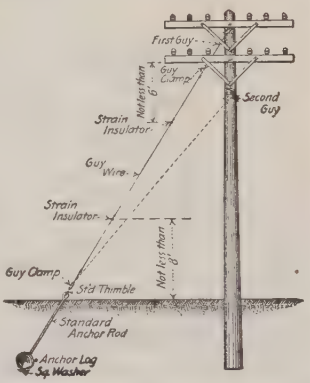


FIG. 78.—An anchor-guyed pole.

92. A guy assembly consists of the following parts:

1. Attachment to pole being guyed.
2. Guy wire containing one or two strain insulators.
3. Attachment to stub pole or to lower part of another pole; or, ground anchor, anchor rod, attachment of strand, and guard.

93. Some of the methods of making up a guy on a pole are shown in Fig. 77. The method of Fig. 77, I is an easy one when some of the other materials are not at hand. The methods of Fig. 77, II and III, make a neater looking job when the hardware is available. The method of Fig. 77, IV is used at a stub pole. Refer to Sec. **55** for a discussion of the

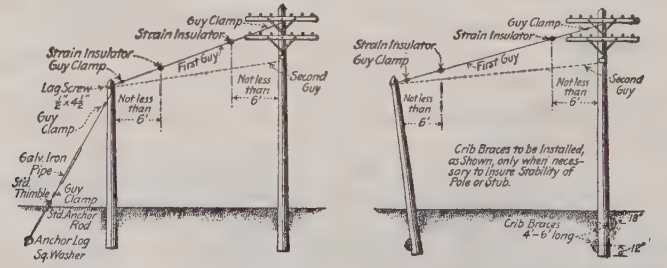


FIG. 79.—Poles guyed to stubs.

hardware required. Where there is but one guy per pole, it is made around the pole just under the top crossarm as shown in Figs. 78 and 79. Where there are two guys to the pole, one is made up just under the top crossarm and one just under the bottom crossarm. Where more than two guys are used, the additional ones should be spaced as equally as possible between the top and the bottom guys that are made up under the top and bottom crossarms, respectively. Where there are two or

more guys to a pole, each should be independent of the others. The different guy wires should not cross one another. Where two or more guys support a pole, a turnbuckle should be inserted in all but one to equalize the stresses.

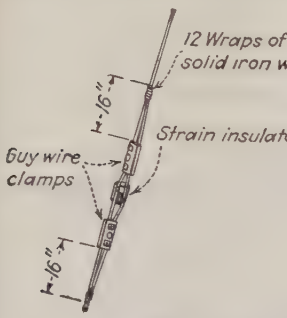


FIG. 80.—Method of making up a strain insulator in a guy strand. (*Hubbard & Co.*)

94. Guy-wire Insulation.—Strain insulators should be inserted in all guy wires to poles carrying electric-lighting or power wires. Two insulators should be inserted in each guy. One is located at least 6 ft. from the pole itself or 6 ft. below the lowest line wire. The other is located at least 6 ft. from the lower end of the guy and at least 8 ft. from the ground. The two strain insulators are sometimes coupled in series in short guys.

The assembly make-up of a strain insulator for a guy is shown in Fig. 80. The two ends of the guy strand are looped through the separate holes in the insulator. The guy-wire clamps hold the wire from slipping, and the No. 12 wrapping wire secures the end of the strand to the guy wire and provides a neat appearance for the assembly.

94A. The number and size of clamps to use for each looped back connection on a guy strand are as follows:

Breaking strength of guy strand, lb.	No. of clamps	Type of clamp	Breaking strength of guy strand, lb.	No. of clamps	Type of clamp
4,000	1	Two bolt	10,000	2	Three bolt
6,000	1	Three bolt	16,000	3	Three bolt

95. The attachment of the guy strand to the anchor rod is shown in Fig. 81. Refer to Sec. **54** and Fig. 42 for description of anchor rods. The

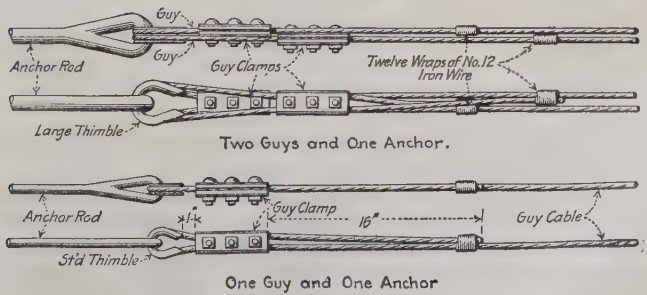


FIG. 81.—Methods of making up guys on guy rods.

eye of the guy rod should extend about 3 ft. above the surface of the earth. Guy rods should not be installed where they will interfere with traffic. A guy protector guard (see Sec. **58**) extending to about 8 ft. above the ground should be placed over anchor guy wires near roadways, as shown in Fig. 79. The foot of an anchor guy should be as far away from the foot of the pole as possible—at least a distance equal to ¼ the height of the pole.

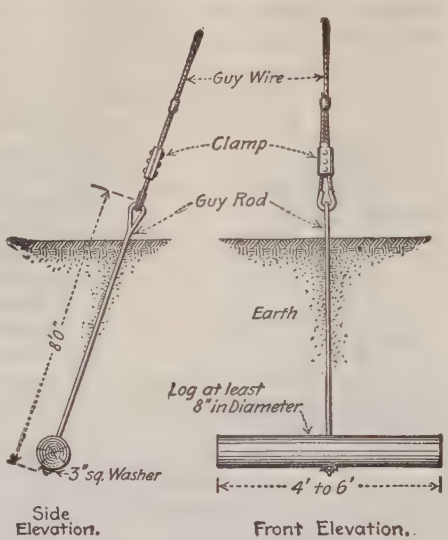


FIG. 82.—A guy rod and anchor.

96. Anchors may be made from logs cut from the tops of old poles (Fig. 82), or patented metal or concrete anchors may be used. Table 97 gives the minimum size for anchor logs and rods and the depth of setting for anchors.

97. Size of Anchor Logs and Depth of Setting for Anchors

Size and number of guys	Min. size of round logs for good soil	Length of rod below ground, ft.	Size of guy rod
One No. 6 Wire or one 4000 lb.	3 ft. × 6 in.	4	7 ft. × ½ in.
One 6,000 lb.	3 ft. × 7 in.	4½	8 ft. × ⅝ in.
One 10,000 lb.	4 ft. × 8 in.	5½	9 ft. × ¾ in.
One 16,000 lb.	5 ft. × 10 in.	6½	10 ft. × 1 in.
Two 6,000 lb.	5 ft. × 8 in.	5½	9 ft. × 1 in.
Two 10,000 lb.	5 ft. × 10 in.	6 or 6½	10 ft. × 1¼ in.
Two 16,000 lb.	6 ft. × 12 in.	6½ or 7	11 ft. × 1½ in.

For the depth and holding strength of patented anchors the catalogues of the particular manufacturer must be consulted.

98. Patented guy anchors can be used in certain kinds of soil very effectively. Figure 83 shows one kind of anchor that is screwed into the earth with a wrench. The resistance of this sort of an anchor to withdrawal from compact homogeneous soils is not determined by the weight of a column of earth the diameter of the anchor screw, but is determined

by that of a cone with sides slanting at 45 deg. and having the point of the anchor as an apex. Figure 84 illustrates this and shows the formula used for computing the withdrawal resistance. Figure 84 shows the anchor inserted perpendicularly, but an anchor should always be inserted at the same angle that the guy wire assumes, so the rod of the anchor will be in a direct line with the guy wire. Section **99** gives the actual resistances to withdrawal of the anchors.

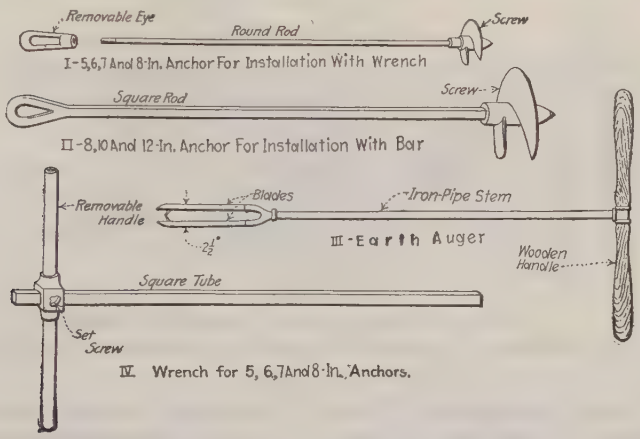


FIG. 83.—Matthews Scrulix anchors and wrenches.

99. The actual holding power of patented guy anchors is an uncertain quantity, except in hard clays ("adobe," "hardpan," or "gumbo") for which Carpenter's formula (Fig. 84) may be used. The safest procedure is to test the anchor's resistance to withdrawal in the soil in which it is to be used. A dynamometer may be employed for measuring the pull. Anchor manufacturers will gladly ship anchors on approval for tests and 30 days' trial. In general, the 5-in. Matthews Scrulix anchor (Fig. 84) should, in other than the hard clays, be used only for the lightest strains, say 1,100 to 2,500 lb., the 6-in. for 1,500 to 2,500 lb., the 7-in. for 2,500 to 5,000 lb., the 8-in. for 5,000 to 7,000 lb., the 10-in. for 7,000 to 10,000 lb. and the 12-in. for 10,000 to 12,000 lb. These holding powers are based on the anchor being screwed into the earth for a depth of at least 5 ft. For anchorages under shallow strands of water or in swampy or caving ground, the 8-, 10-, and 12-in. anchors having the square rods are very convenient.

100. Directions for Installing Matthews Guy Anchors. 5-, 6-, 7- AND 8-IN. WITH RODS.—Remove the eye of the anchor; pass the rod through the wrench and replace the eye, which will serve to hold the wrench rigidly to the anchor, then screw the anchor in, at the same angle as the guy wire is to run, as far as ground conditions will permit. When

in as far as possible, remove the eye and pull out the wrench. Then replace the eye, thus making anchor ready for guy wires. The handle bars of the wrench are adjustable and held in place with a setscrew. They can be moved back as the anchor screws in.

8-, 10-, 12-IN. WITH RODS.—Place bar or other lever in eye of anchor and screw it in as far as ground conditions will permit, always at the angle

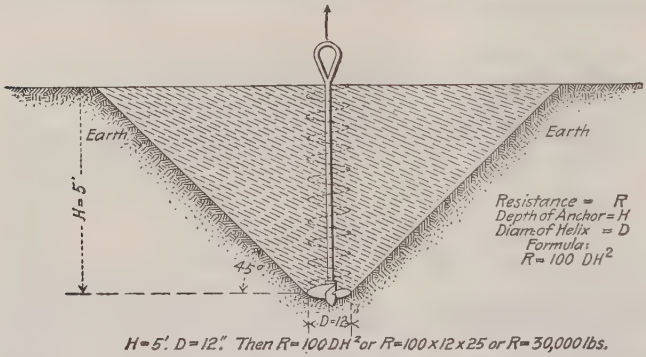


FIG. 84.—Illustrating Carpenter's formula for resistance of Matthews anchor to withdrawal.

that the guy wire is to run. Time will be saved and the anchor will start easier if a few spadefuls of earth are removed before starting anchor. When the anchor is set, attach the guy strand to the eye. Always pull anchor back as far as possible before finally tying the guy wire.

IN DRY, HARD GROUND.—In setting all anchors in hard ground, the work will be much easier if a small hole is first made with an earth auger

FIG. 85-I.—Details of tree blocks.

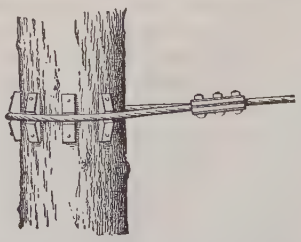


FIG. 85-II.—Guy wire fastened to tree.

(Fig. 83), a crowbar, or a wood auger with a long shank. This renders the insertion of the anchor easier. A little water poured down this hole before starting the anchor will help considerably where the ground is hard and dry. In installing 8-, 10-, and 12-in. anchors in very hard ground, clamp a lever to the rod by means of a chain, a foot or so above the ground. As the anchor is screwed down, the lever can be moved up.

The anchor will start more easily if a few spadefuls of earth are removed at the angle desired to set the guy. If a man stands on the helix of the anchor when starting until the point bites the ground, it will assist.

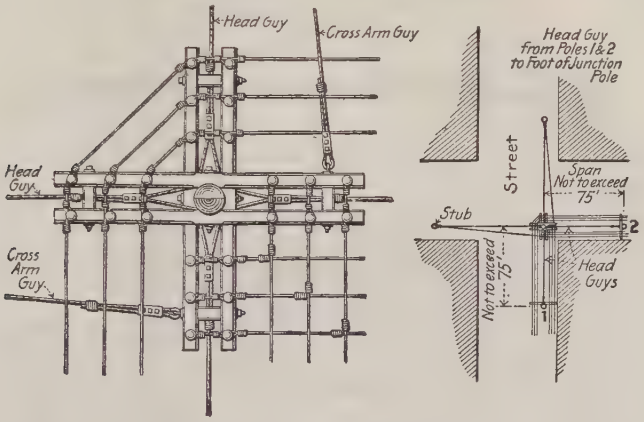


FIG. 86.—Method of turning corner with one pole.

In localities where loose gravel or small flat rock occurs, drill a hole with an earth auger, a digging bar, or a crowbar, as suggested above. If a small rock is encountered, it can be broken by the bar. If a large rock is "discovered," the bar can be removed and the hole drilled in another place. This will allow the use of anchors in many places where otherwise it would seem impossible to install them.

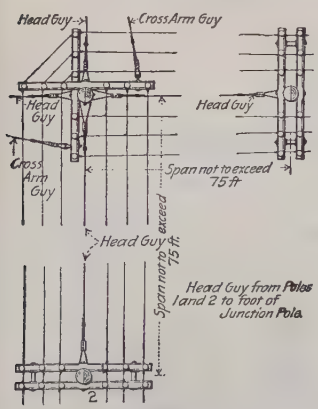


FIG. 87.—Corner pole without double arms.

101. The methods of installing stub guys are shown in Fig. 79. The stubs should be long enough so that the guy wires will clear roadways by at least 18 ft., sidewalks by 15 ft., and electric wires by 3 ft. Stubs are used only when a line cannot be guyed properly to trees or poles. Stubs should satisfy the specification for poles as given in Sec. 8.

102. In guying to a tree, tree blocks (Fig. 85) should be used, and the wire should pass but once around the tree. Tree guying is undesirable and should not be done unless absolutely necessary. Guys should preferably be attached to trunks or to limbs that are not less than 8 in. in diameter. Do not attach to a limb that will swing with the wind and sway the

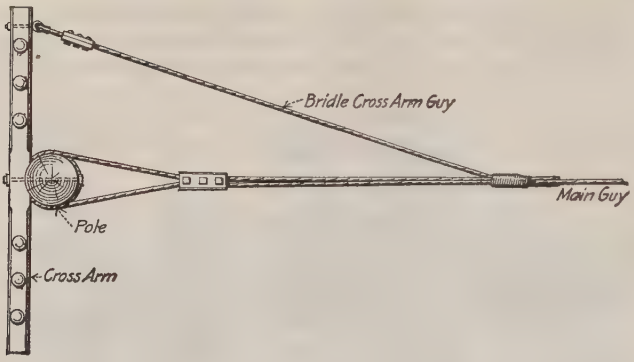


FIG. 88.—Bridle guy.

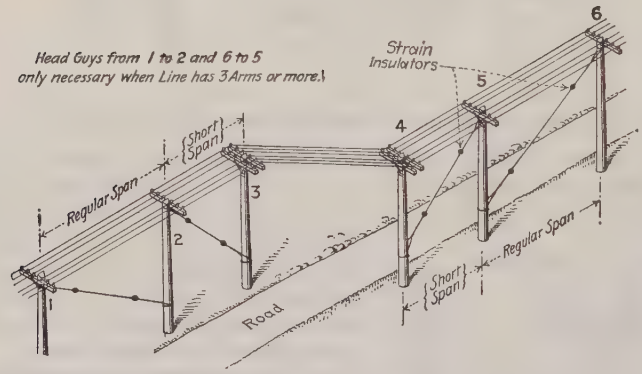


FIG. 89.—Guying at road crossing without side guys.

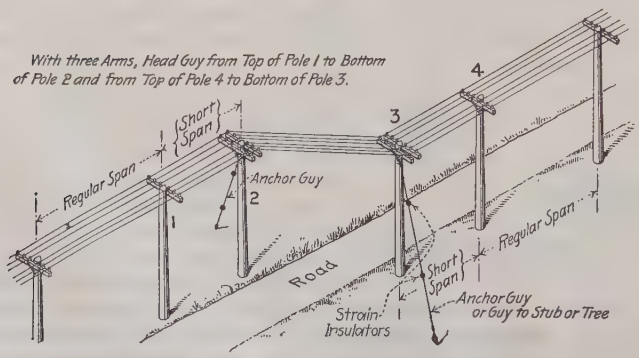


FIG. 90.—Guying at road crossing with side guys.

pole. Enough tree blocks should be used so that the guy wire cannot touch the tree.

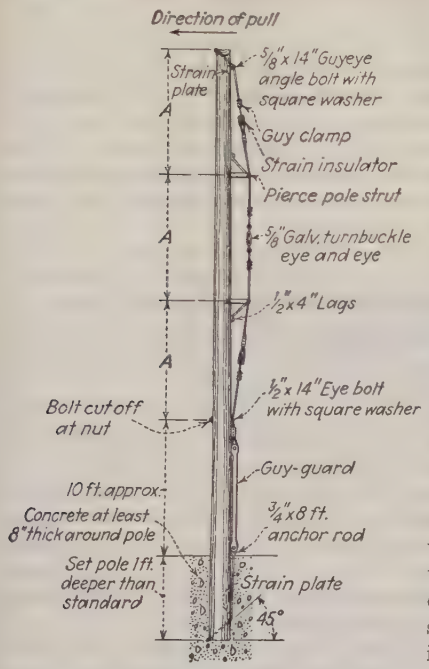


FIG. 91.—Details of self-supporting pole.

103. Crossarm guys are used where the pull on a crossarm is unbalanced. Figures 48, 86, and 87 show examples. Crossarm guys usually extend from the arm to a pole or stub, but sometimes for light strains the Y or "bridle" guy (Fig. 88) is used.

104. A line must be thoroughly guyed where it crosses a road. Figures 89 and 90 show two methods of holding a line at such a point. The method involving the use of side guys is preferable, but the other one will give good service where side guys cannot be installed.

105. Where it is impossible to secure guying privileges along the desired route for a line, or where obstructions make guying difficult, the problem is generally solved by the use of self-supporting poles, a construction commonly referred to as "hog guying." This method of strengthening a pole is especially useful on corners, around curves, and at points where space is too limited for ordinary guying. The method of hog guying is illustrated in Fig. 91.

105A. Pole braces are used where guying is not feasible. They cost more than equivalent guys. Figure 92 shows methods of bracing poles. The upper end of each brace fits in a notch cut in the pole and is bolted thereto.

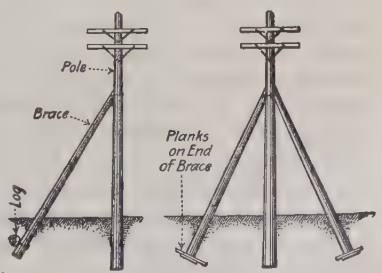


FIG. 92.—Bracing poles.

UNDERGROUND WIRING

106. Underground systems are of three main types:

1. Duct line.
2. Cable buried directly in the ground.
3. Conduits located in tunnels.

A duct line consists of one or more conduits spaced close together with or without a concrete casing. The duct line is laid in a trench with the top at least 2 ft. underground and covered over with earth; it should be covered with pavement if it is located under a street. The duct lines terminate in underground vaults, called manholes, where transformers and protective equipment are located and where cable splices are made. The cables are drawn into the ducts from one manhole to the next. This system is ordinarily used for general underground distribution work where there is more than one cable located in the same run or where the cable may have to be increased in size or replaced.

With the system in which the cable is buried directly in the ground, a trench is dug, and the cable, which is of a type to resist the corrosive effects of the ground (called parkway or nonmetallic-armored cable, see Div. 2), is laid in the trench without any protection other than that afforded by the cable insulation and earth covering (refer to Sec. **139** for further details). This method is used for single-circuit runs where the load is apt to be steady and definite, as in street or parkway series-lighting systems. This method is also used for underwater lines where the construction of a duct line would be difficult or impossible.

For groups of buildings in an industrial plant or institution, where tunnels between buildings must be constructed for steam and water lines, it is quite common to locate the electrical circuits in conduits on the walls of the same tunnels.

107. Commercial conduit duct materials are fiber, wood, vitrified tile, iron pipe, asbestos composition, and monolithic concrete.

108. Fiber conduit is widely used for ducts in underground construction. Fiber conduit is made of wood pulp which is treated and thoroughly saturated with a bituminous compound. The compound contains about 6 per cent of creosote to prevent rotting. The different sections of conduit are joined by means of self-aligning joints. They may be laid in the trench with great rapidity. The cost of laying fiber conduit is considerably less than for tile duct owing to its lightness and to the greater length of sections, which require fewer joints. Fiber conduit permits cables to be drawn into it readily because of its smooth oily interior. The ducts are laid in concrete with walls 3 in. thick on all sides. Generally, a spacing of 3 in. is employed between the different ducts of a run.

The standard sizes (nominal inside diameters) are 2, 2½, 3, 3½, 4, 4½, and 5 in. On the smaller sizes the wall is ¼ in. thick; the 4½-in. size has a 5/16-in. wall, and the 5-in. size has a ⅜-in. wall. The standard length is 5 ft., but lengths as short as 3 ft. may be obtained as part of an order of standard lengths.

109. Creosoted wood ducts are low in cost but will probably decay in time. Their life is said to be about 20 years if thoroughly creosoted. Wood ducts are inflammable and may burn in case of a short circuit within them.

110. Vitrified-clay single duct or hollow brick is the most popular for communication cables and is sometimes used for low-voltage power work. Figure 93 shows a typical length. The inside diameters of the round ducts are 3¼, 3½, 4¼, and 4½ in. A 3½-in. square size is also available. The single duct is preferred because its walls are thick and in laying every joint is broken, eliminating the possibility of the arc of a short circuit on one cable affecting cables in other ducts in the same run. Single ducts can also be more readily laid around obstructions such as pipes, and, furthermore, curves can be more readily formed with them than with multiple ducts.

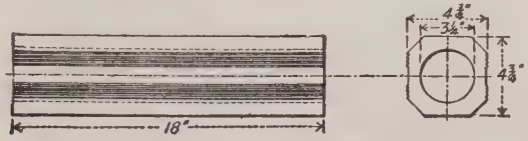


FIG. 93.—A piece of single duct.

111. Vitrified-clay multiple duct is frequently used for communication cables on account of the ease of assembly. The four-way multiple duct is the most popular size (Fig. 94), although the six-way duct is frequently used. Nine-, twelve-, and sixteen-way multiple ducts can be manufactured, but they are seldom used because of their excessive weight and liability to breakage. The dimensions of the multiple ducts of a certain nominal size made by different manufacturers vary. Those shown in Fig. 94 for a four-way duct are typical. A 3¼-in. square size is also

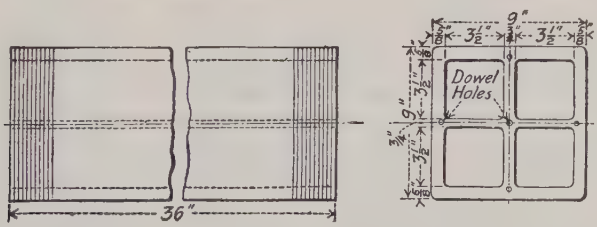


FIG. 94.—A piece of multiple duct.

available. Two- and three-duct sections are 24 in. long; the others 36 in.

112. Iron pipe is sometimes used for duct lines, but since it costs more than the other materials it has not had general acceptance for this purpose. One important advantage is that it gives the cables better protection from damage during excavation. Wrought-iron pipe is preferable to steel pipe, which is often sold for wrought iron, because the wrought iron resists corrosion much more effectively than does steel. See index for dimensions of wrought-iron conduit which are the same as those for

wrought-iron pipe. Iron pipe is frequently used to carry parkway lighting circuits, especially if they are laid in filled ground which might be injurious to cable laid directly in the ground. The principal use for iron pipe in underground work is for laterals (see Sec. **122**).

113. Asbestos composition conduit, called Transite, is made from asbestos fibers and cement rolled on steel mandrels under pressure. It is strong, light in weight, highly resistant to corrosion, incombustible, and noninductive and has low frictional resistance and high thermal conductivity for dissipating the heat from the cables. It is made in sizes from 2- to 6-in. iron-pipe size in 10-ft. lengths, except that the 2- and 2½-in. sizes come in 5-ft. lengths only. There are two grades, a light weight called Korduct, which should be used where concrete incasing construction is required owing to poor soil or where the duct is incorporated in building construction, and a standard weight called Transite conduit. The standard weight may be used without concrete protection where the soil condition is reasonably good. It may also be used exposed to the weather on the sides of bridges or buildings. Transite Conduit without concrete encasing will run 10 to 30 per cent cheaper than steel or fiber duct encased in concrete. Joints are made with a tapered Harrington coupling (Fig. 95, I) into which the two ends of the conduit make a sliding wedge fit. In concrete work a tin-plate coupling (Fig. 95, II) with flared ends, into which the conduit fits, is commonly employed. For exposed installations, expansion couplings (Fig. 95, III) are used to take up vibrations, expansion and contraction due to temperature changes, and movement between the supporting structure and the duct. One-half of the expansion coupling has a larger diameter than the conduit. A durable rubber ring is installed between the conduit and the large-diameter half of the coupling which seals the joint and allows a movement of at least ¾ in. in either direction from the median. For severe weather conditions an expansion coupling should be used every 30 or 40 ft. Where the duct is protected from sun, rain, and freezing, as on the underside of bridges or within buildings, one expansion coupling every 50 to 100 ft. may be sufficient. Table 114 gives dimension and weights of Transite Conduit and Korduct.

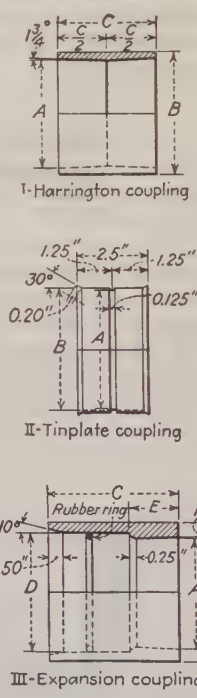


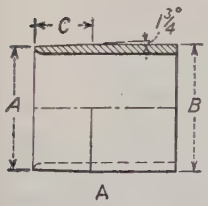
FIG. 95.—Couplings for Transite conduit. (*Johns-Manville Co.*)

114. Standard Dimensions and Weights of Transite Conduit and Korduct

Transite Conduit				Transite Korduct			
Size, inside diam., in.	Wall[a] thickness, in.	Standard[b] length, ft.	Weight[a] lb. per ft.	Size, inside diam., in.	Wall[a] thickness, in.	Standard[b] length, ft.	Weight[a] lb. per ft.
2	0.30	5	2.1	2	0.20	5	1.2
2½	0.30	5	2.6	2½	0.20	5	1.5
3	0.32	10	3.3	3	0.22	5	1.8
3½	0.32	10	3.7	3½	0.22	10	2.0
4	0.32	10	4.1	4	0.22	10	2.3
4½	0.35	10	5.1	4½	0.22	10	2.8
5	0.35	10	5.7	5	0.25	10	3.2
6	0.35	10	6.7	6	0.25	10	3.7

[a] Wall thickness and weight subject to a tolerance of plus 15 per cent. Weights shown for Transite Conduit include one Harrington coupling per length and those for Transite Korduct include one tin-plate coupling per length.

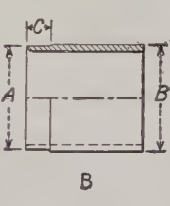
[b] Right is reserved to ship up to 15 per cent in lengths shorter than standard, each length being a multiple of 6″.



Size	A	B	C
2	2.49	2.60	1.75
2½	2.99	3.10	1.75
3	3.53	3.64	1.75
3½	4.03	4.14	1.75
4	4.52	4.64	2.00
4½	5.08	5.20	2.00
5	5.58	5.70	2.00
6	6.58	6.70	2.00

Size indicates nominal inside diameter of conduit in inches.

The ends of Transite Conduit are machined to a standard taper of 1¾ deg. to fit Harrington couplings.



Size	A	B	C
2	2.26	2.40	1.00
2½	2.76	2.90	1.00
3	3.31	3.44	1.13
3½	3.81	3.94	1.13
4	4.30	4.44	1.25
4¼	4.80	4.94	1.25
5	5.35	5.50	1.38
6	6.34	6.50	1.50

Size indicates nominal inside diameter of conduit in inches.

Transite Korduct ends are tapered, on special order, to fit Harrington couplings.

115. Monolithic concrete ducts may be built in two ways: (1) by using flexible Para rubber tubing as a core, (2) by using a duct-forming machine called a boat. In the rubber-tubing method, thick rubber tubes which are flexible but not readily collapsible are laid on a concrete base and separated with terra-cotta spacers. Concrete is then poured around them as in the other methods. When the concrete has set for a few hours the tubings are withdrawn, leaving a very smooth concrete duct. In the

boat method a track is built at the bottom of the trench. On this track runs the boat, which is really a die containing as many steel tubes as the number of ducts wanted. Concrete is fed into a hopper at the top and is tamped down around the tubes. The boat is moved slowly along the track either by hand or by power from an electric motor, leaving the finished duct extruding from the rear. The concrete is of a special mixture which is sufficiently solid to hold the form of the ducts as the boat moves along.

The rubber-tubing method is especially advantageous where the duct line must be threaded around other underground structures and pipes. It may be used to advantage in bringing duct lines into power stations and substations, as the duct may be formed in one continuous run from

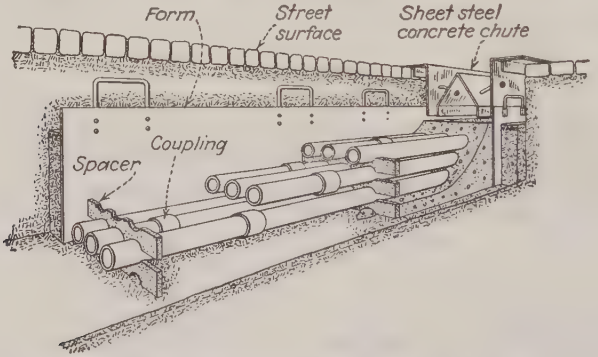


FIG. 96.—Construction of duct line. (*Johns-Manville Co.*)

the street manhole to the switching-gallery floor. The main advantage of the boat method as well as the rubber-tubing method is that there is no material in the duct to decay. Both methods have proved more expensive than using fiber or asbestos conduit so that for normal straight runs they cannot compete economically. For special irregularly shaped curves a section of the monolithic concrete duct, formed by the rubber-tubing method, may well be inserted even if the main run is made with one of the other materials.

116. In installing any kind of a duct line a trench is excavated to such a depth that the top conduit will be 2 to 3 ft. below the surface of the ground and so that the grade of the duct line will pitch toward the manholes about 1 ft. in 100 ft., so as to ensure effective drainage. For power cables the ducts should be arranged either two conduits wide or two conduits deep so that every conduit will have earth on at least one side of it. This is necessary for conduction, into the cooler ground, of the heat generated by the I^2R losses in the cables. For communication cables the heat loss is low, and the ducts may be arranged in any con-

venient way. There should be from 1 to 3 in. of earth or concrete between conduits for power systems to ensure that flame and heat from a short circuit in one conduit will not affect the adjacent cables. The 3-in. separation should be used on the higher voltage lines. Conduits are held in position during construction of the duct line by wooden spacers (Fig. 96). The width of the trench will depend on the working space required and on whether concrete and concrete forms are used or not. With Transite Conduit concrete is not required unless the soil is not firm. If the soil is firm, the trench may be merely 1 or 2 in. wider than the space required by the conduits. With other conduits, where concrete is required, it should be about 3 in. thick outside the conduits. In good firm soils the trench may be dug to exactly this width and forms omitted,

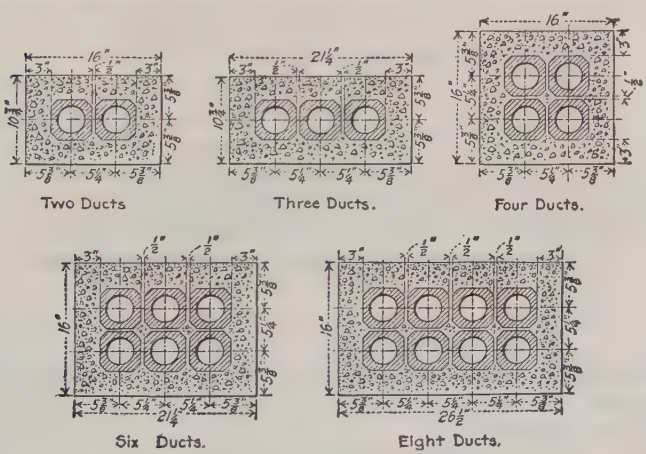


FIG. 97.—Arrangement of single-duct subway.

the concrete occupying all the space between the conduits and the earth wall. In ordinary and poor soils the trench should be made an additional 3 in. wider on each side to provide space for installing the forms.

The bottom of the trench should be carefully rammed until solid so that undue stress will not be placed on the conduits. With concrete construction the 3-in. bed of concrete is then laid, over which the lower tier of conduits is placed with spacers to ensure the correct separation between conduits. Then the concrete is tamped around them, and thus each level is built up until the duct is completed with 3 in. of concrete on top. In laying Transite Conduit in firm soil, the process is similar except that earth takes the place of the concrete. Sometimes the spacers are removed after the conduits are held firmly in position by the backfill and before the spacers are completely covered over. At other times the spacers are left in to form a permanent part of the duct line.

117. Installing Single-duct, Vitrified-tile Conduit.—(See Fig. 97 for sections of duct runs.)

After the bed is set, the duct is laid in cement mortar. A mandrel (Figs. 98 and 99) is used to keep the successive pieces in line. It is customary to enclose the conduit in a continuous concrete encasement 3 to 4 in. thick.

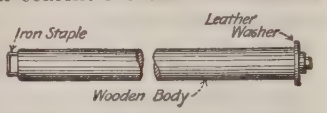


FIG. 98.—Mandrel for aligning conduit.

The mandrel is pulled through with a long hook as the conduit progresses, to align the ducts. The leather washer scrapes away any mortar that has oozed through between joints and leaves the duct quite clean. The end of a No. 12 galvanized-iron wire is frequently attached to the

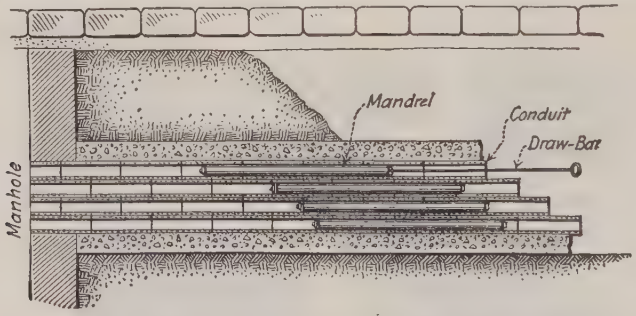


FIG. 99.—Showing use of mandrel.

inner end of the mandrel and is pulled into the conduit as its construction progresses. The wire is used to pull in the drawing-in rope which is used to pull in the cable.

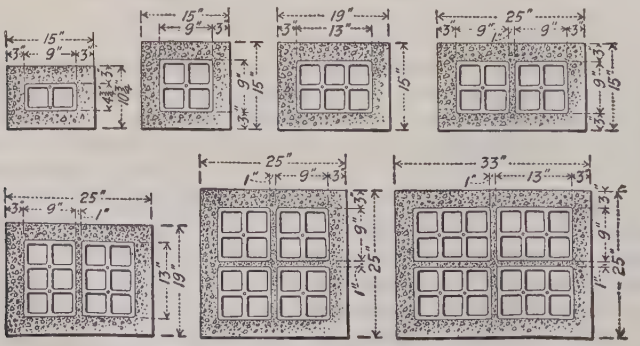


FIG. 100.—Sections of multiple duct.

The single ducts furnished by some manufacturers are provided with male and female ends, which assist in aligning the ducts.

118. Laying Multiple Duct.—Multiple duct is laid in about the same way as single duct. Figure 100 shows sections of multiple-duct runs. The pieces are laid end to end, and the joints, if there is more than one tier in the subway, are broken. The pieces are maintained in alignment by iron dowel pins or keys (Fig. 101), which fit in holes in the pieces. All joints are wrapped with pieces of burlap or coarse muslin, 4 in. wide and 3 ft. long for four-duct tile, which are moistened to make them stick. They are then coated with cement. The cloth prevents the entrance of cement or concrete into the ducts.

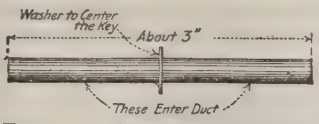


FIG. 101.—Steel key for multiple duct.

Sometimes a mandrel (Fig. 98) ¼ to ½ in. smaller than the hole is drawn through as the construction progresses, as suggested in Fig. 99, to ensure alignment of the pieces. The handle on the mandrel should be long enough to reach back two joints so that one may be sure that the last three pieces set align, as they may have become displaced in setting.

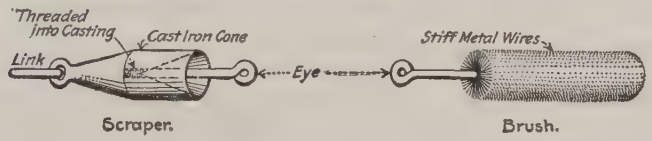


FIG. 102.—Scraper and brush for conduit.

After the pieces are set, be careful that they are not displaced before the concrete jacket is deposited. The ducts should be cleaned out after the concrete jacket has been placed by drawing a wire brush or flue cleaner (Fig. 102) through them. The brush is somewhat bigger than the duct hole. Sometimes a metal scraper (Fig. 102) is also used.

Multiple duct has been laid without any concrete casing, but with merely a concrete bed, as suggested in Fig. 103. This construction is economical in first cost but is apt to give trouble through settling of the earth or displacement due to future excavation. Creosoted boards are sometimes laid on top of a conduit run to protect against laborers' picks. Experience has shown that the average laborer will stop when his pick strikes a board, but that he will pick his way through concrete or duct material. Multiple-duct conduit can be carried around obstructions, as shown in Fig. 104, by beveling the ends of the pieces. If the turn is too short it may be difficult or impossible to "rod" the duct and to pull the cable in.

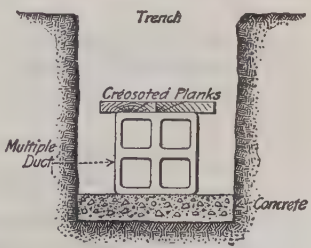


FIG. 103.—Protective planks over multiple duct.

119. To cut vitrified conduit a groove is chipped completely around the piece on the line at which it is desired to cut it. A hammer and cold chisel are used for chipping the groove. Usually it will break off on the chipped line after continued chipping, but it may not. Some experience is required before one becomes skillful at this work. Short lengths can be furnished by the conduit manufacturers and their use is recommended.

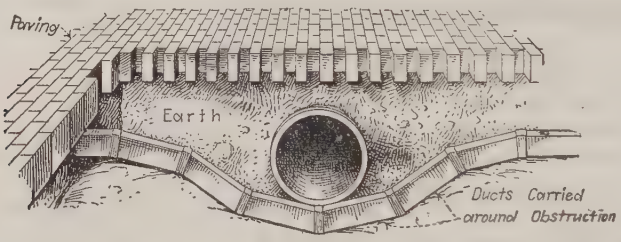


FIG. 104.—Breaking around an obstruction with vitrified duct. (Where possible, the bend should pass *over* rather than under the obstruction. When it passes under the obstruction, water will collect in the pocket).

120. In installing iron-pipe conduit no concrete casing is considered necessary if only one duct is involved. Where there are several ducts in the run, the ducts are sometimes laid on a 3-in. foundation of concrete and concrete is tamped between and around the ducts as shown in Fig. 97 for single vitrified duct. Where the ducts will not be exposed to the dangers of future excavation the cost of the concrete is probably not justified. Iron pipe is sold usually in 20-ft. lengths. Joints between adjacent lengths are made with ordinary pipe couplings. See Index

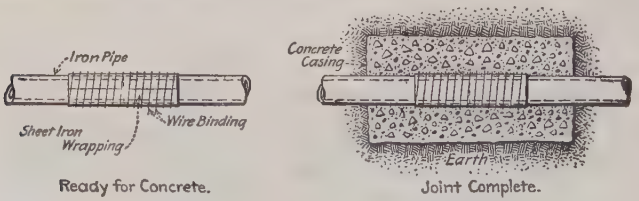


FIG. 105.—Cement joint on wrought-iron pipe.

for dimensions of conduit and fittings, which are the same as those for pipe. The burrs at the ends of pipe lengths must be carefully removed to prevent damage to the cable. Where it is inconvenient to use a coupling, a pipe union can be used instead or the fitting can be omitted (Fig. 105) and the abutting ends encased in a block of concrete. The ends should be wrapped with a piece of sheet iron wired in position before the concrete is applied. Iron pipe for conduit is sometimes painted, inside and out, with asphalt, but this is not considered necessary by all engineers.

121. Concrete for conduit work should be clean, *i.e.*, foreign substances should not be permitted to enter into its composition. If the surface on which it is to be mixed is not smooth and clean, mixing boards or pans should be used. Foreign material impairs the strength of concrete, and it becomes porous and leaky. The concrete should be mixed from Portland cement, clean sand, and gravel or broken stone, in the proportions, by volume, of 1 part of cement to 3 parts of sand and 5 parts of gravel or stone. Just sufficient water should be used to wet the mixture thoroughly and to permit a small amount of water to come to the surface when the concrete is tamped into final position. The cement, sand, and stone should be "turned" on the mixing board at least three times dry and at least twice after wetting. The concrete should be placed immediately after mixing. When the concrete has been placed in the trench, several hours should be allowed for it to take its initial set before the trench is filled in. This is necessary to prevent throwing the ducts out of alignment, or fracturing the "green" concrete.

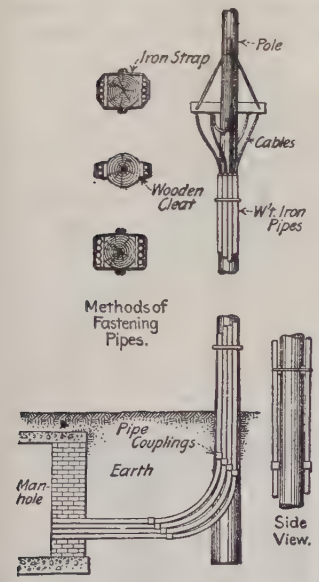


FIG. 106.—Wrought-iron pipe laterals.

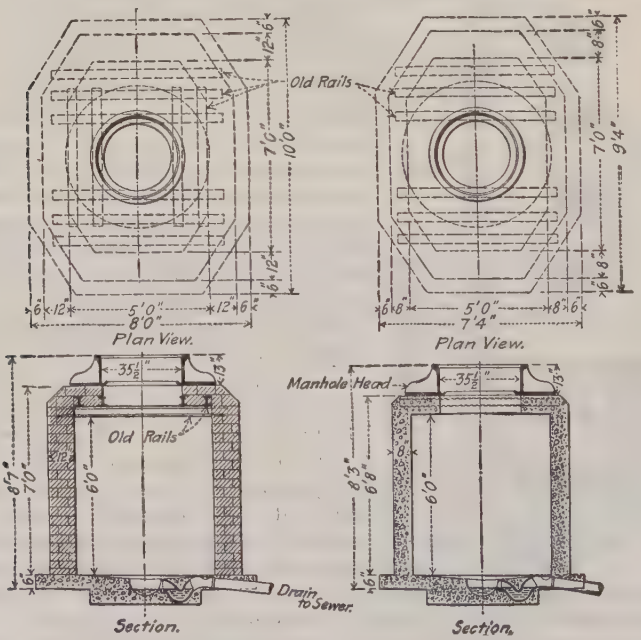
122. For laterals which carry the service cables from the duct lines to the buildings served, concrete construction is usually not justified. For this purpose Transite Conduit may be used, although iron pipe has been more commonly employed for this purpose. Iron pipe may be bent at will, and it is frequently necessary to thread a network of underground structures with a lateral, especially if it has to cross the street. Usually wrought-iron pipe is used because the wrought iron resists the corrosive effect of the ground. An application of iron pipe in changing from overhead to underground construction is illustrated in Fig. 106.

123. Manholes are necessary in a subway system to permit of the installation, removal, splicing, and rearrangement of the cables. A manhole is merely a subterranean vault or masonry chamber of sufficient size to permit of proper manipulation of the cables. The conduits enter the vault, and on its sides devices are arranged whereby the cables within the manhole can be supported.

The location of manholes is determined largely by the layout of the district that is to be supplied with power. Wherever a branch or lateral extends from the main subway there must be a manhole, and there must

be manholes at intersections of subways. In general, cables are not made in lengths exceeding from 400 to 600 ft. and, as it is necessary to locate splices in manholes, the distance between manholes cannot exceed these values. Furthermore it is not advisable to pull in very long lengths of cable, because the mechanical strain on the conductors and sheath may then become too great during the pulling-in process. It is recommended that manholes be located not more than 500 ft. apart (see Sec. **147**).

124. Manholes are made of many shapes and sizes to meet the ideas of the designer and to satisfy local conditions. It is established, however,



I-A. 5- by 7-ft. brick manhole. II-A. 5- by 7-ft. concrete manhole.
FIG. 107.—Typical manholes.

that the form shown in Fig. 107 is best for the average condition. Where there are obstacles about the point where a manhole is to be located, the form of the manhole must be modified so as to avoid them. The form approximating an ellipse (Fig. 109, I) is used so the cables will not be abruptly bent in training them around the manhole. In using the rectangular type of manhole (Fig. 109, II) care must be taken not to bend the cables to a sharper radius than is allowable as given in Div. 2.

The size of manholes will vary with the number of cables to be accommodated, but in any case there must be sufficient room to work in the

manhole. A 5- by 7-ft. manhole (Fig. 107) is probably as large as will be required in isolated plant work, while a 3- by 4-ft. manhole (Fig. 108) is about as small as should be used. When transformers are located in a manhole, the size should be increased to allow for working space around the transformer and for ventilation. About 2 or 3 cu. ft. of volume should be allowed per kilovolt-ampere of transformer rating.

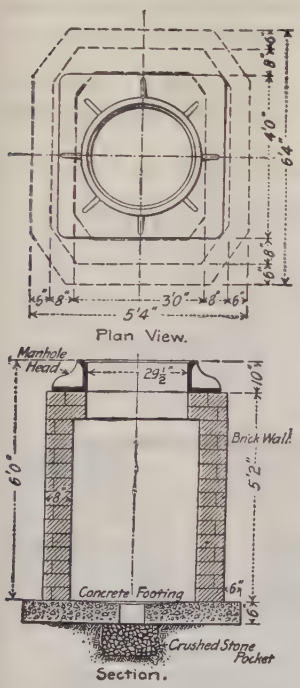
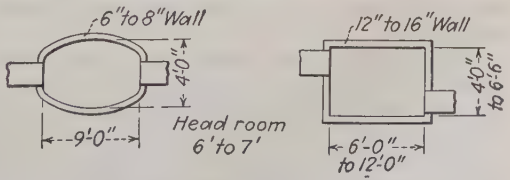


FIG. 108.—A 3- by 4-ft. manhole.

Manholes are built of either brick or concrete, or of both of these materials. Where many manholes are to be built of one size and there are no subterranean obstructions, concrete is usually the cheapest and best material. But where only a few are to be constructed or where there are many obstructions a manhole with a concrete bottom, brick sides, and a concrete top is probably the best. Such a manhole can be constructed without having to wait for concrete to set before forms can be removed and, furthermore, no forms, except some planks to support the top, are necessary.

125. A concrete manhole is built by first depositing the concrete floor (Fig. 107, II) and then erecting the form for the sides on this floor. In a self-supporting soil the sides of the hole constitute the form for the outside of the manhole. If the soil is not self-supporting, an outer form of rough planks must be made, which is usually left in the ground. Steel reinforcing—old rails are good—must be placed in the concrete top of a large manhole. In a small manhole the manhole head or cover will extend over the side walls, and no reinforcing, or manhole roof for that matter, is required. All reinforcing steel should be completely encased in concrete to prevent corrosion.



I-Elliptical II-Rectangular

FIG. 109.—Types of manholes.

126. A manhole with brick walls is built (Fig. 107, I) by first depositing the concrete floor and then building up the brick walls thereon. Where

the manhole is large the roof can be of either steel-reinforced concrete or brick set between rails. Probably for installations where only a few manholes are to be built the brick-between-rails method is the best. For a small manhole no masonry roof is necessary, as the cast-iron manhole head forms the roof.

Cement mortar for building brick manholes or for conduit construction can be made by mixing together 1 part of cement and 3 parts of sand and about ⅓ part of water, all by volume.

127. Distribution or service boxes, so called, which are really small manholes, often serve the purpose of, and can be used instead of, larger vaults in industrial and isolated plant installations. A design for a concrete service box is shown in Fig. 110. A brick one would be of approximately the same dimensions. The depressions in the side walls are sleeve pockets. The splicing sleeves on the cables lie partially in these, after installation, and therefore less of the valuable working space of the box is occupied by them. In spite of the fact that a square manhole cover can fall into the hole, heads with square covers are often used for distribution boxes so as to provide an orifice giving maximum working room.

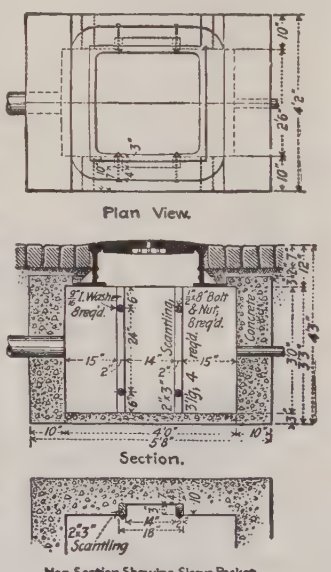


FIG. 110.—A concrete service box.

128. Manhole heads are frequently made of cast iron, but cast steel is better; the cover should always be of cast steel. Figure 111 shows a design for cast iron, for a large manhole, and Fig. 112 one for a smaller manhole. Covers should be round so that they cannot drop into the hole accidentally.

So-called watertight covers are now seldom used as it is not feasible to make a satisfactory watertight cover at reasonable expense, and water gets into the manholes in any event. Covers should not be fastened down because, if they are and accumulated gas in a manhole explodes, the vault and cover will be shattered. A ventilated cover should be used in order to allow the escape of gas. The newer types have ventilating slots over approximately 50 per cent of their area. Dirt and water will get into the hole, but the dirt can be cleaned out and the water will drain out and no harm will result. If ventilation is not provided an explosion of gas may occur and do great damage.

129. Draining Manholes.—Where feasible, a sewer connection should lead from the bottom of every manhole (see Fig. 107, II). The mouth of the trap should be protected by a strainer, made of noncorrodible wire, such as that used for leader pipes. Where a sewer connection cannot be made there should be a hole in the manhole floor so that water can drain out. A pocket under the manhole filled with broken rock will promote effective drainage (see Fig. 108).

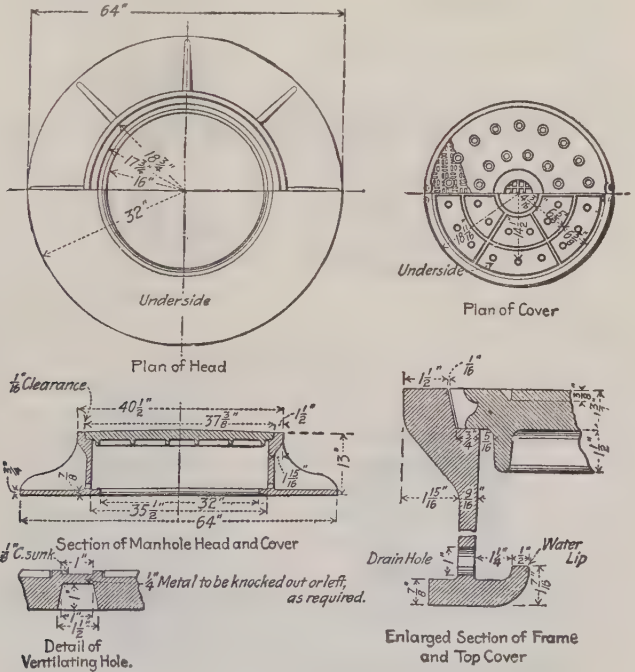


FIG. 111.—Head for large manholes.

130. At the point where a conduit line enters a manhole the walls should be chamfered off as shown in Fig. 113 to prevent the damage that might occur if a cable is bent over a sharp corner.

A precast conduit entrance may be made up on forms on the surface of the ground and then lowered into position in the side of the manhole. One type using porcelain duct bells is shown in Fig. 114. The smooth curved surface of the bell prevents the cable sheath from being cut where it starts to bend coming out of the duct line.

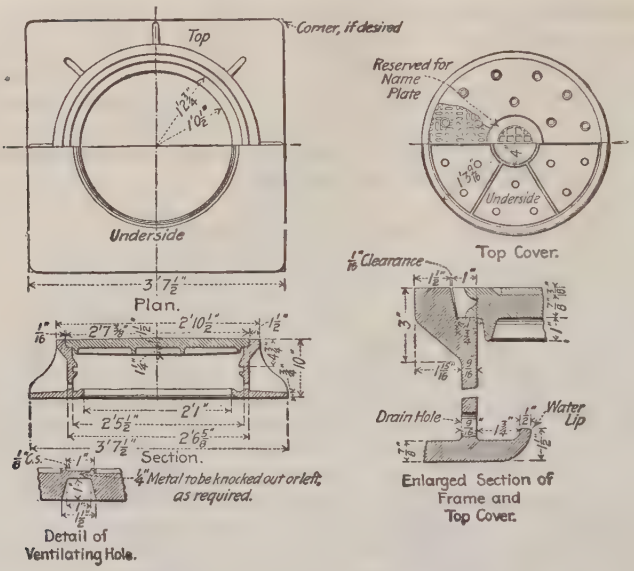


FIG. 112.—Head for small manholes.

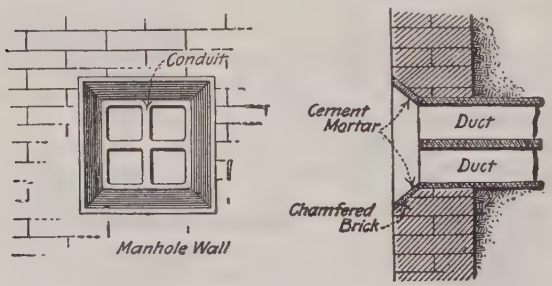


FIG. 113.—Chamfered wall at conduit entrance.

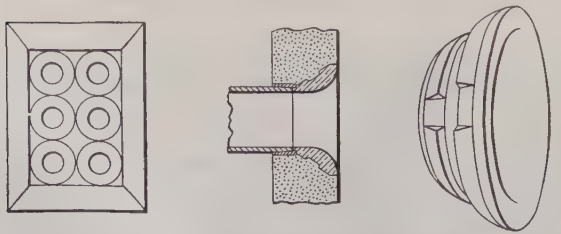


FIG. 114.—Manhole duct entrance using porcelain bells. (*Line Material Co.*)

131. A manhole hook, a convenient tool for removing manhole heads, is shown in Fig. 115. A common pick can be used, but the tool shown is much more convenient.

132. **In installing cables in conduit,** if a pull-in wire was not installed at the time the ducts were placed, the conduit is rodded, a pull-in wire

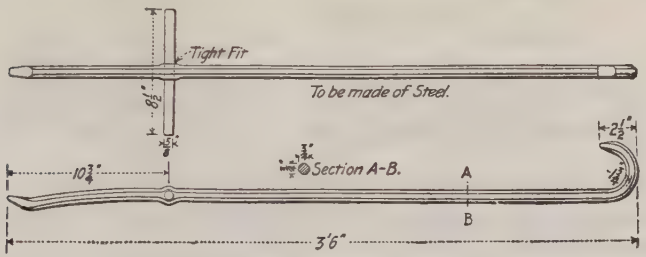


FIG. 115.—A manhole hook.

or the drawing-in cable is drawn through, cleaners are pulled through, and then the cable is drawn in.

133. Rodding.—Rods are pieces of round hickory about ¾ in. in diameter and 3 ft. long (see Fig. 115*A*). The ends of the rods are equipped with brass knuckle-joint fittings so the rods can be readily joined together and disjoined. In rodding, a rod is pushed into the duct and a second rod is coupled to it. The two are pushed into the duct, and a third rod joined on, and the process is repeated until the rods extend from manhole to manhole. A galvanized-iron wire is attached to the last rod, and the wire is drawn into the duct.

A rope or flexible steel cable to which are attached a scraper and a brush (Fig. 102) is drawn through to ensure that the duct is clear and

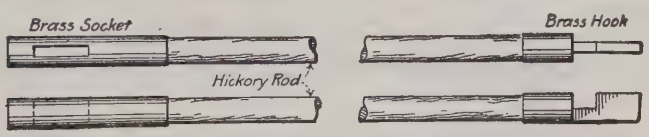


FIG. 115*A*.—Rods for conduit.

clean. To the end of this rope or cable another is attached which is used to pull in the electrical conductor cable.

Where the conduit is short, a steel fish wire or ribbon, like that used by electricians in wrought-iron conduit work, can be inserted instead of the rods. Sometimes a "fish" made of lengths of flexible bamboo is used instead for laterals and other short runs.

134. **Pulling In Cable.**—The cable can be attached to the pulling-in wire by any one of several methods. Figure 116, *C* shows one that was formerly much used. Probably the best methods are those illustrated in Fig. 116, *A* and *B*. At *A*, a galvanized iron wire is laced around the

cable in such a way that the harder it is pulled the tighter it grips. At *B* is shown a "grip" spirally laced from flexible steel strands. It slips over the cable sheath readily, but when tension is applied it effectively grips the cable. A swivel should always be inserted in any pulling-in

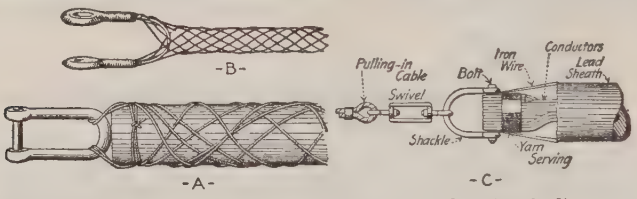


FIG. 116.—Methods of attaching cable to drawing-in line.

line to prevent the untwisting of the drawing-in line under tension from twisting the cable.

After the cable is fastened to the pulling-in line a "protector" is placed in the mouth of the duct to prevent abrasion of the cable. Metal pro-

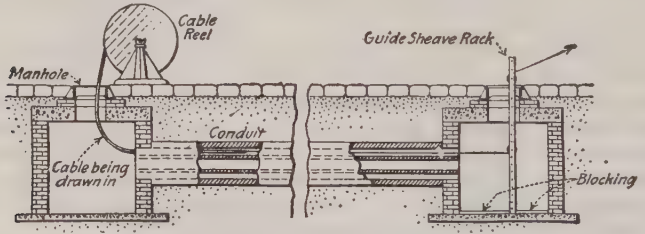


FIG. 117.—Drawing in cable with winch.

tectors can be purchased, but a good one can be formed from a piece of sole leather.

The cable is bent, as shown in Fig. 117, from the cable reel to the mouth of the duct, and the pulling in commences. In the far manhole,

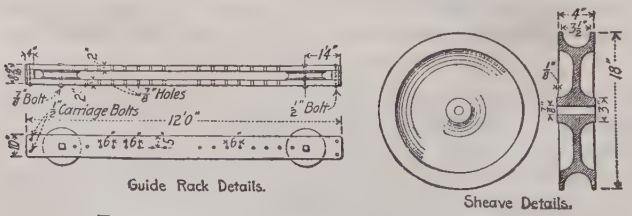


FIG. 118.—Guide sheave, rack, and sleeve.

sheaves are arranged over which the pulling-in line passes (see Fig. 117). If eyebolts were built in the manhole sides, the sheaves (snatch-blocks) can be fastened to them. Otherwise a guide-sheave rack (see Fig. 118 for detail and Fig. 117 for application) can be set up in the manhole.

A winch, truck, tractor, or horses can be used for the pulling. Men can pull a cable in if the run is not too long. The cable sheath should be greased as it is drawn in, to ensure easy pulling. Where a length of cable longer than the distance between manholes is to be pulled through, it can pass over the sleeves on the guide-sleeve rack, provided they are large enough in diameter. Refer to Tables 135 and 136 in Div. 2 for minimum allowable bending radii of cables. A manhole capstan (Fig. 119) is sometimes used instead of a winch on the surface of the ground. Enough cable should be pulled into the manhole to allow for forming it around the hole and splicing it. Do not permit a cable to hang over the sharp edge of a duct. Support it in the rack.

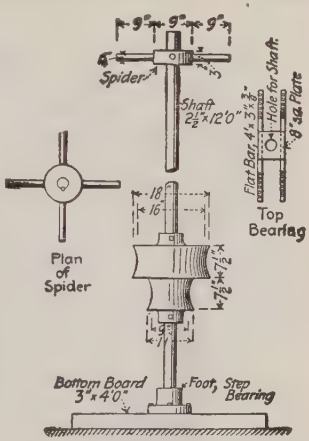


Fig. 119.—Manhole capstan.

135. Supporting Cables in Manholes. Some provision must be made for supporting cables. Creosoted planks (Fig. 120) are sometimes bolted to the manhole sides, and the cables are held to the cleats with pipe straps. In other cases metal supports are used, several forms of which are on the market. One that can be readily made is shown in Fig. 121. A rack made of porcelain arms on a steel framework is shown in Fig. 122.

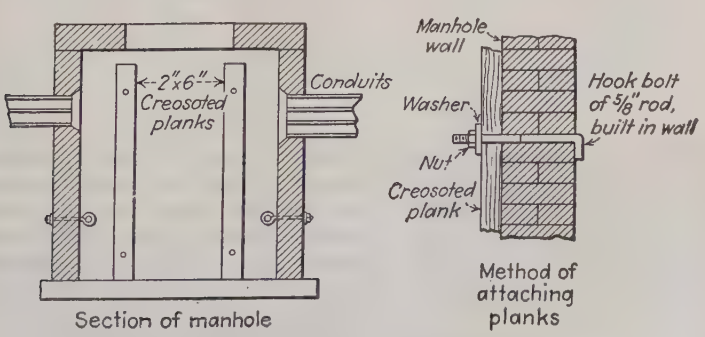


Fig. 120.—Cresoted plank cable supports.

136. Eyebolts or stirrups should be set in manhole walls to provide means of attachment for the tackle used in pulling in cable (Fig. 120). An eyebolt or stirrup should be set opposite the point of entrance of each subway. Figure 123 shows the dimensions of a suitable stirrup.

137. Several cables should not be placed in one duct. Experience has shown that, although it is easy enough to install cables under such

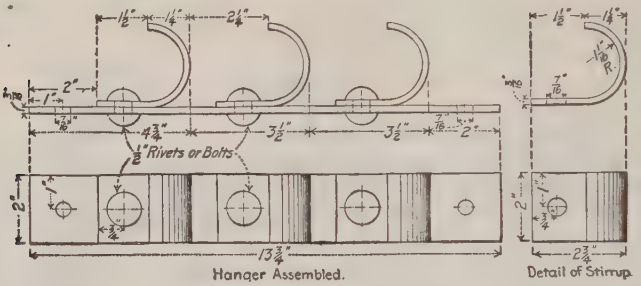


FIG. 121.—Iron cable support.

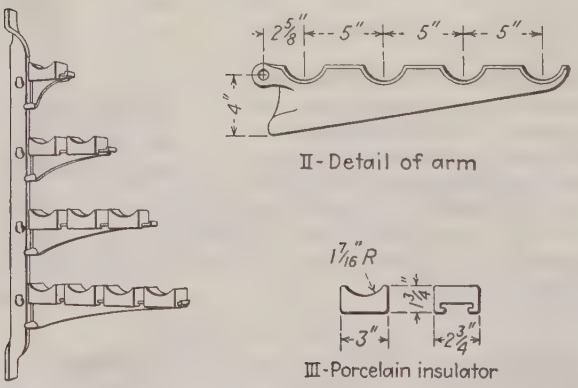


FIG. 122.—Cable rack. (*Line Material Co.*)

conditions and mechanically easy to withdraw them, the removal almost invariably ruins the cable, because after long lying in a duct the cables become so impacted with dust and grit that when one is drawn out the sheath is either stripped from the cable itself, or from one of its companions. Consequently, conduits are now almost exclusively built by arranging a sufficient number of ducts so that each cable may have its own exclusive compartment.

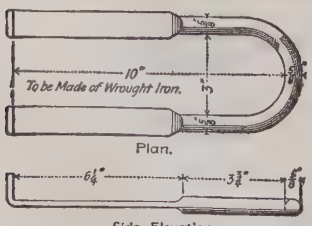


FIG. 123.—Stirrup for manhole wall.

The maximum diameter of a cable that may be installed in a duct, as recommended by the Edison Electric

Institute, is given in Sec. 32 of Div. 11. For cable diameters refer to Div. 2.

138. In manholes and ducts cables should be so arranged that there will be a minimum of crossing and recrossing. An underground cable system should be carefully planned, and the ducts should be so chosen for the cables that, as far as feasible, a cable will take the duct in the same relative position throughout the subway.

139. Installation of Cable Buried Directly in the Ground.—Cable buried directly in the ground finds a wide field of application for installations of single circuits where the cost of duct construction would be prohibitive. Some of the more common applications are:

1. Street-lighting circuits, especially in cities whose outlying sections are without ducts.
2. Lighting and power circuits in parks, on estates, in industrial plants, on bridges, etc.
3. Connecting residences to mains, especially subdivisions and underground service in alleys.
4. Connecting houses, garages, and other buildings.
5. Railroad-yard and airport lighting.
6. Lighting and power circuits for amusement parks, baseball, football, and general sports.
7. High-wall power cable for strip mines.
8. Railway-signal circuits.
9. Crossings under small lakes and streams.
10. Horizontal runs in mines for power, lighting, and telephone circuits.

Both nonmetallic-armored cable and metallic-armored cable (parkway cable) are used for direct burial in the earth. Refer to Div. 2 for description of these cables. The nonmetallic-armored types are lighter in weight, more flexible, and easier to splice, are not subject to rust, crystallization, induced sheath power loss, or trouble from stray currents. On the other hand, they do not give such good protection against mechanical injury.

The cables are installed either by digging a shallow open trench, laying in the cables, and refilling, or by means of a special plow, which is available on a rental basis. When a trench is dug, it needs to be made only wide enough for convenient handling of the cable. The cables need not be laid more than 12 to 18 in. under the surface except where subject to extreme mechanical hazard, such as at street intersections or under roadways. At such points it is advisable to bury the cable at least 30 in. deep and to cover the cable with sections of planking.

DESIGN OF DISTRIBUTION INSTALLATIONS

140. In designing an installation of conductors for the distribution of electricity there is no royal road. It is rather a cut-and-try process, and frequently, for a reasonably large installation, many tentative layouts

must be made before the most suitable one is found. The design of such layouts is affected by so many conditions that only the most general suggestions can be given. Review the information on circuits in Div. 3 of this book.

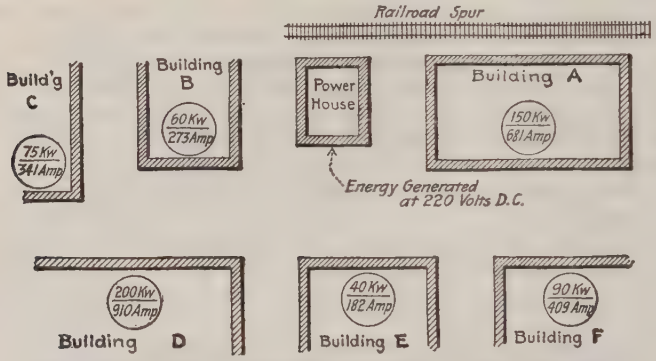


FIG. 124.—Power and current demands in an industrial plant.

141. In laying out any electrical distribution system the first step, if the system is of any consequence, is to note, on a scale map of the territory to be served, the locations at which electricity will be required and the amount of power that will be taken at each. In general, each building in

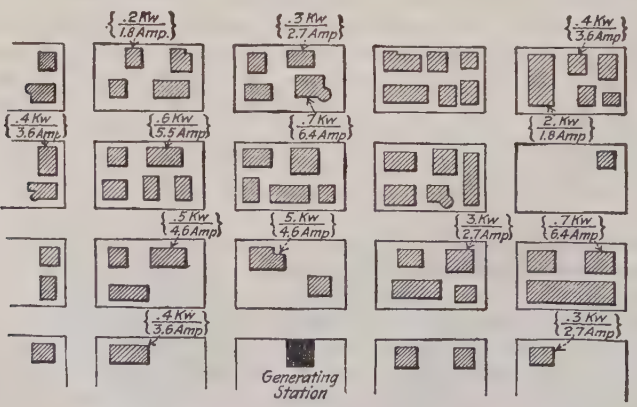


FIG. 125.—Power and current demands in a small town.

the area to be served is considered as a unit, as it is seldom advisable to install more than one service to a building, except that for the different buildings of an industrial plant separate services from the plant distribution system are generally provided for lighting and for power, and possibly for emergency or night lighting. Figure 124 shows such a layout

for an imaginary industrial plant and Fig. 125 for a portion of a town. The values within the circles indicate the maximum power demands. The figure above the horizontal line is the power demand in kilowatts and the one below the line is the current. The power factor must be considered if the system is to be alternating current. If separate circuits are to be maintained for light and for power, which is usual practice, the power demand for each circuit should be noted. In the illustrations (Figs. 124 and 125) it is assumed, for simplicity, that power and lighting devices are served from the same circuits. The current is noted in addition to the power demand because it is necessary to know the current to determine the capacities of fuses and switches and to check conductor sizes for current-carrying capacity and voltage drops.

142. Layout of Feeders and Mains.—After the locations of the points where energy will be required have been plotted and the amount of power that will be required at each has been noted, the feeders and mains can be laid out and the conductor sizes for them calculated. No hard and fast directions can be given. Each case must be treated individually in accordance with the conditions to be satisfied. The following factors should be given careful consideration: (1) cost of the conductors and their supports; (2) energy loss in the conductors; (3) reliability of operation; (4) satisfactory voltage regulation. Sometimes considerable expense is justified to secure exceptionally good reliability and close voltage regulation, while in other cases reliability and close voltage regulation are less important. Whether the distribution conductors are to be carried overhead—on poles or buildings—or underground will affect their routing.

143. The magnitude of load that should be served by one feeder or main is altogether a relative matter and depends to an extent upon the flexibility of control and of metering desired and on the station capacity. In industrial plant installations if it is desired to meter in the generating station the energy supplied to different departments or buildings, obviously an individual circuit must be carried from the switchboard to every such building. It should be possible to disconnect portions of the load at the powerhouse in case of trouble with the generators or in case a heavy load increase is thrown suddenly on the station. In this way an emergency may be met without shutting down the entire plant. In general, in a small station, the load on any feeder should not be larger than can be readily carried by any one of the generating units, and it is better to have the load further subdivided. Usually a load divides itself naturally into convenient units because of the arrangement of buildings, groups of buildings, departments, or other topographical or commercial considerations.

144. Mains are sometimes tapered. A tapered main is one in which the conductor size diminishes from the point of source of energy outward (see Fig. 126). It is usual, and ordinarily the best, practice to use a main

of the same size conductor throughout its length. Splices and intermediate cutouts are thereby avoided. Theoretically, a tapering main, assuming a given maximum drop, does not effect a saving in copper as is often but erroneously believed.

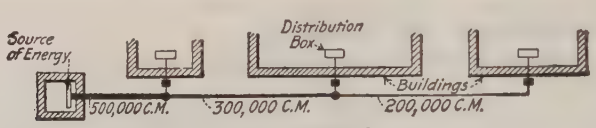


FIG. 126.—A tapered main.

145. The calculations of wire sizes for feeders and mains for distribution installations are made similarly to those for interior circuits. Methods and examples of calculation for the different systems are given in Div. 3.

146. Overhead vs. Underground Distribution.—Whether overhead or underground distribution should be used depends in the case of small or medium-sized installations very largely on how much can be spent for appearances. An overhead system, properly installed, can be made thoroughly reliable and will usually cost much less than an equivalent underground system. Sometimes in industrial-plant work it is necessary to build subways for pipes in any event, and when such subways can also be utilized for electrical conductors a low installation cost may be possible.

147. If the distribution conductors are to be carried underground in conduit it is necessary to group the runs as far as possible, as suggested in

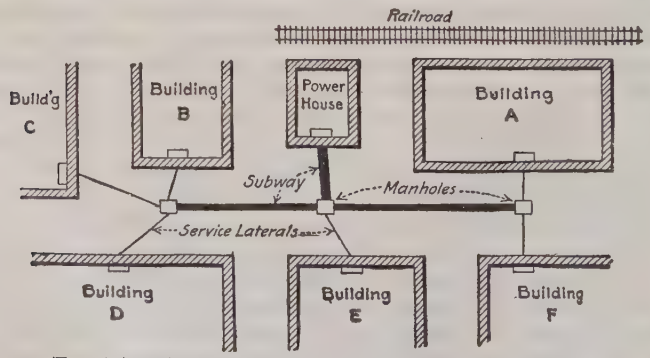


FIG. 127.—Conduit system for underground distribution.

Fig. 127, to ensure minimum cost for excavation and manholes. The lines should preferably be run straight between manholes. If curves are necessary the offsets from a straight line and the distance between manholes should not exceed the values given in the following tables:

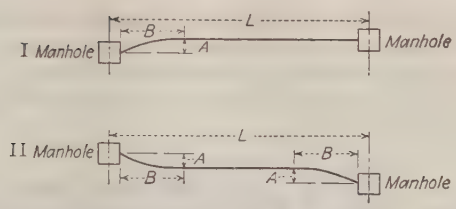


FIG. 128.—Offsets for main duct line. (I) Single curve. (II) Reverse curve.

(I) Single curve				(II) Reverse curve			
A Curve offset	*B* Min. length curve, ft.	Max. length *L* between manholes, ft.		*A* Curve offset	*B* Min. length curve, ft.	Max. length *L* between manholes, ft.	
		4 ducts	6–16 ducts			4 ducts	6–16 ducts
0′ 1″	5	800	700	0′ 1″	5	800	700
0′ 3″	10	740	650	0′ 3″	15	740	650
0′ 6″	15	685	600	0′ 6″	25	655	575
0′ 10″	20	640	560	1′ 0″	35	570	500
1′ 3″	25	600	525	1′ 6″	40	515	450
1′ 9″	30	570	500	2′ 0″	45	485	425
2′ 4″	35	545	475	2′ 6″	50	455	400
3′ 0″	40	515	450	3′ 0″	55	435	380
3′ 9″	45	485	425	3′ 6″	60	420	365
4′ 7″	50	470	410	4′ 0″	65	400	350
5′ 6″	55	445	390	4′ 6″	70	385	335
6′ 6″	60	425	370	5′ 0″	75	365	320
7′ 6″	65	400	350	6′ 0″	80	345	300
8′ 9″	70	370	325	7′ 0″	85	320	280
10′ 0″	75	345	300	7′ 6″	90	310	270

148. If the distribution conductors are to be carried overhead, more direct routes can be selected, for, with overhead distribution, conductors in industrial-plant work can be carried over buildings in the most direct routes.

149. A combination main, feeder, or other circuit is one that serves all energy-consuming devices, motors, lights, and minor miscellaneous equipment.

150. An independent main, feeder, or other circuit is one that serves only motors and similar equipment or only lighting devices.

151. Independent vs. Combination Circuits for Lights and for Motors. One of the first things to be decided is whether individual circuits from the switchboard out will be used for lighting and for motors. It is desirable to use independent circuits because it is then possible, at reasonable expense, to maintain a much closer voltage regulation and hence

steadier illumination in the lighting circuits. Furthermore, since troubles such as heavy short circuits and grounds occur more often on motor circuits than on lighting circuits, the possibility of such troubles throwing a building or an area in darkness is minimum with independent motor and lighting circuits.

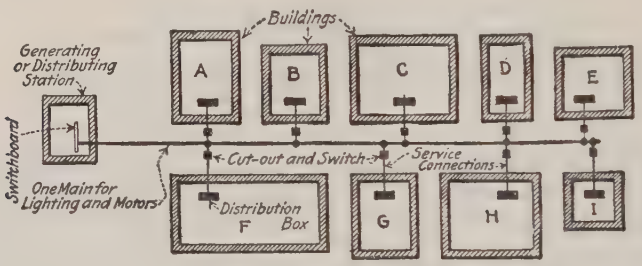


FIG. 129.—Combination main for lighting and motors.

152. Main and feeder layouts for industrial plants are shown diagrammatically in Figs. 129 to 134. Although these apply principally to industrial-plant installations, the principles involved are the same as for municipality electricity distribution. However, because of the different conditions, municipality distributions are handled somewhat differently. In these diagrams, which illustrate principles rather than actual installations, *A*, *B*, *C*, *D*, etc., represent the buildings in an indus-

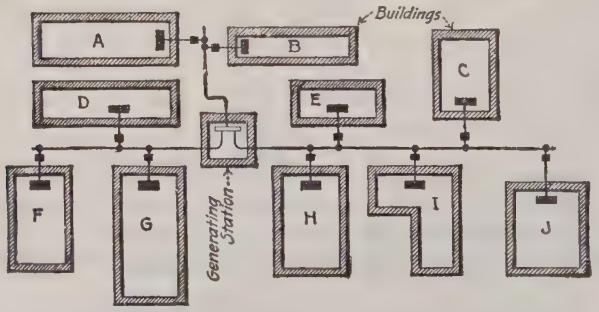


FIG. 130.—Combination mains serving groups.

trial plant. A single line represents an entire circuit, two wires for a d-c, two-wire circuit; three wires for a three-wire circuit, etc. The diagrams apply to any system of distribution. The service wires from the distribution circuits enter the buildings and terminate in distribution boxes—panel boxes or groups of cutouts. From the distribution boxes the interior motor and lighting circuits, which are not shown, are supposed to radiate. For information regarding the layout of interior wiring circuits, refer to Div. 9 on Interior Wiring.

153. A combination main for lighting and motors (Fig. 129) can be used where the installation must be of minimum expense. In the illustration a single main, which may be carried underground, on poles, or on fixtures attached to the buildings, extends from the switchboard. Service connections are tapped from the main for each building or group of buildings and are terminated in a distribution box—a panel box or a group of porcelain cutout fittings—within the buildings. Since the service conductors will be smaller than the main conductors, a cutout and, preferably, a switch are inserted in each. The only thing to commend a layout like that of Fig. 129 is its low first cost. With such a layout the voltage regulation on the lighting circuits is apt to be poor, and a ground or short circuit on any circuit may put the entire plant out of commission. With this arrangement the station operator has no control over the use of the power, and if he wishes to decrease the load on the generators by cutting off certain portions of the plant he has no means of doing so. It is an example of "all the eggs in one basket."

154. Independent mains for lighting and motors (Fig. 131) are sometimes used. This is a better arrangement than that of Fig. 129 in that

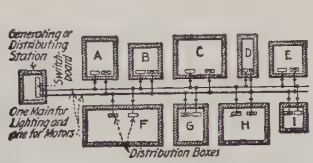


FIG. 131.—Independent main for lighting and one for motors.

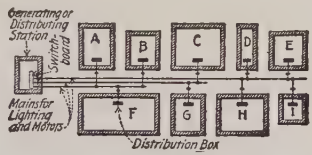


FIG. 132.—Combination mains serving groups.

the lighting circuits are entirely separate from the motor circuits. But if many lights or many motors are served by one main, trouble is apt to occur. Furthermore, it is not possible to control the power supply of each building from the generating or distributing station.

155. Combination Mains Serving Groups (Fig. 132).—This is a modification of a single combination-main layout and is sometimes used and is permissible in certain instances where the installation cost must be low. It is better than a single combination-main arrangement, but is not very good as no arrangement is good where lights and motors are fed from the same circuit, unless the motor load is relatively unimportant. The station operator has some control over his load and the load is sufficiently sectionalized so that all "eggs are not in one basket." Figure 130 shows another example of combination mains serving groups.

156. Independent Mains Serving Groups (Fig. 133).—This is a fairly good arrangement if the groups are not too large. Its possible disadvantages are that with it, it is not feasible to meter the energy to each unit in the group at the generating station nor is it possible to disconnect each unit from the generating station. These are not always

disadvantages. Such an arrangement judiciously laid out will give excellent service.

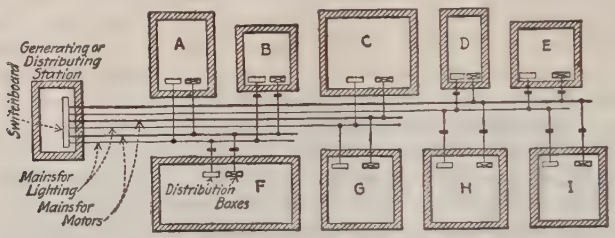


FIG. 133.—Independent mains serving groups.

157. Combination feeders (Fig. 133*A*) possess the advantages that the load is well divided—"few eggs in a basket"—and that each feeder circuit can be readily controlled and metered at the generating station. But they possess the disadvantages, already enumerated, that always obtain where lighting appliances and motors are served by the same circuit. In general, such a layout is not to be recommended, though it may give satisfactory service where the conditions are not exacting.

158. Individual feeders (Fig. 134) provide the ideal layout for reasons that have been suggested in preceding paragraphs. It is seldom that it is advisable to run a feeder to every building in a group. A combination of the methods of Figs. 133 and 134 is usual. Individual feeders are

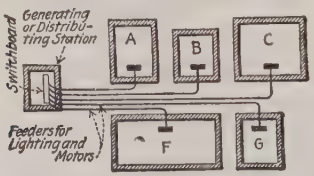


FIG. 133*A*.—Combination feeders for lighting and motors.

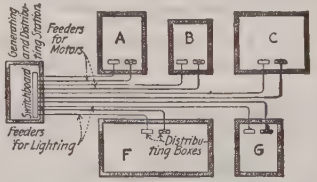


FIG. 134.—Independent feeders for lighting and independent feeders for motors.

carried to the principal buildings, and mains are arranged on the group plan to serve the buildings having small loads.

159. A d-c, two-wire distribution is seldom used for any installation except a small industrial plant. The voltage may be either 120 or 240. If most of the load is lighting, 120 volts may be used. But, if the load is of any consequence, the conductors will be very large for 120 volts; hence 240 is more often used. The feeders and mains in an industrial plant can be laid out in accordance with any of the methods of Figs. 129 to 134, but, as outlined in connection with those illustrations, the methods of Fig. 133 or 134 are to be preferred. See Sec. **69** of Div. 10 for information in regard to the disadvantages of operating incandescent lamps at 240 volts.

160. Direct-current, three-wire distributions are frequently used in industrial plants where there are many adjustable-speed motors for machine-tool drive and the like. Direct-current, three-wire distributions are also still in existence in some municipalities. In either case the voltages are almost invariably 115 to 230. The best method for an industrial plant is suggested in Fig. 134*A*, wherein separate feeders are carried from the switchboard to each building or group of buildings for

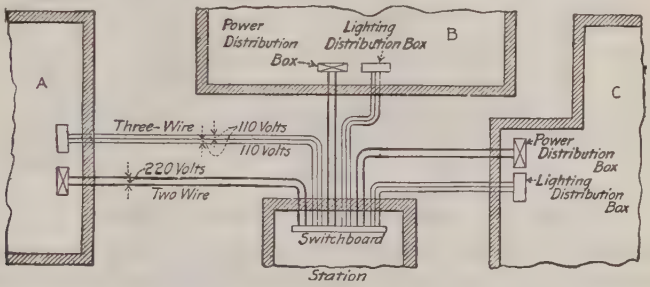


FIG. 134*A*.—Three-wire distribution.

lighting and for power service. The lighting feeders are three-wire so that the incandescent lamps can be operated at 110 volts. The motor feeders are usually 220 volts, two-wire, unless some scheme of motor-speed control is used that requires all three wires.

161. Single-phase, a-c, high-voltage distributions are seldom used in industrial plants but are often used in municipalities. The voltage is usually 2,300. In a municipality, a feeder can be installed to serve each district (Fig. 135) and an automatic potential regulator can, if necessary, be cut into the feeder and arranged to maintain the voltage constant at the center of distribution. If no regulator is used, the feeder might connect into the nearest point, as *A* (Fig. 135), of the distribution system. Consumers are served through transformers which reduce the voltage (see Fig. 136) from 2,200 to 110 or 110/220, three-wire (see the division on Transformers). Small single-phase motors of capacities smaller than, say, 5 hp. may practically always be supplied from the same secondary conductors which carry the lighting load. But a separate service should, in general, be run for motors of capacities greater than, say, 10 hp. As to whether or not a separate service should be installed for motors, local conditions should govern in each individual case.

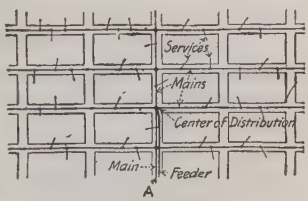


FIG. 135.—Primary distribution in a municipality.

Figure 136 shows methods of serving customers. Single transformers are used for detached customers. Where several customers are grouped

it is good practice to run a secondary main supplied by one or more transformers. Through this arrangement the use of small transformers is avoided, and the investment in transformers is decreased. Large transformers are more efficient than small ones.

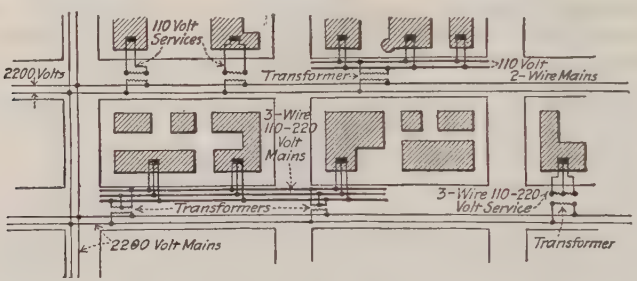


FIG. 136.—Single-phase, high-voltage distribution.

Secondary mains are usually made three wire (Fig. 136), and the advantages of the three-wire system (see Div. 3) are thereby realized.

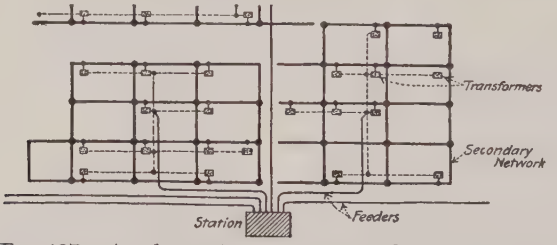


FIG. 137.—An alternating-current secondary network.

Where the load is dense, the secondary mains may be tied together into a network (Fig. 137). Closer regulation and maximum utilization of the

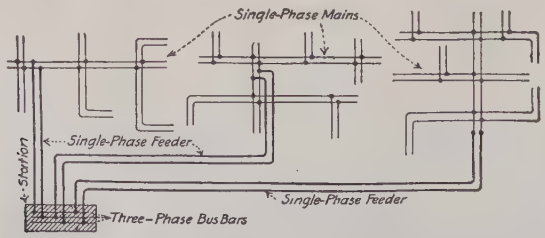


FIG. 138.—Single-phase distribution in a municipality.

copper are thereby assured. Such a network is usually 115/230 volts, three-wire. Some companies will not employ secondary networks because of the difficulty in locating and clearing trouble on them. In

modern practice, single-phase generators are seldom built. Alternating-current generators are usually three-phase, but feeders may be single-phase, and they are tapped from three-phase bus bars as suggested in Fig. 138. The single-phase loads should be approximately balanced on the three phases.

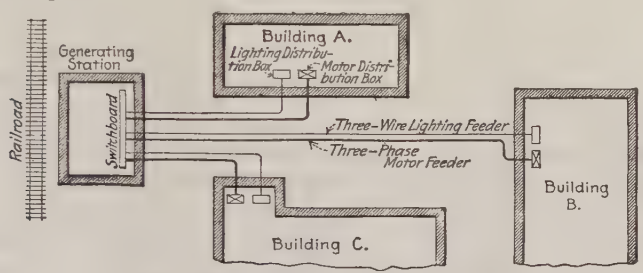


FIG. 139.—Three-phase individual feeder layout.

162. Three-phase, low-voltage distribution systems are commonly used in medium-sized industrial plants. The voltage is either 120/208 volts four-wire or 440 volts three-wire. The general trend of practice is toward the use of 440 volts where the motor load is large. The 120/208 volts eliminates the expense of transformers for lighting and does very well where the motors are not larger than about 10 or 15 hp. Figures

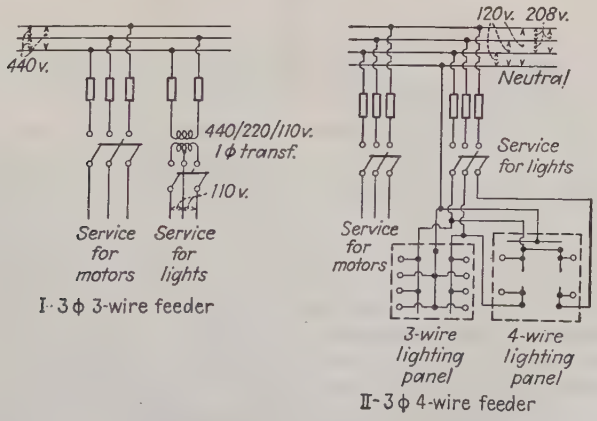


FIG. 140.—Connections for three-phase motor and lighting service.

139 and 140 illustrate what is probably the best layout for a three-phase industrial-plant system. Individual motor feeders operate at either 208 or 440 volts, and three-wire, single-phase lighting feeders operate at 110/220 when supplied from the 440 volts through single-phase transformers or at 120/208 volts when supplied direct from the four-wire,

208-volt system. Lighting panel boards may be connected either three- or four-wire.

Individual three-phase motors with the 440-volt system are supplied at that voltage; small fractional-horsepower, single-phase motors are supplied from the lighting system. With the 120/208-volt system, three-phase motors are supplied at 208 volts, three wire. Single-phase motors are supplied at 120 volts, two-wire.

Any of the schemes of distribution suggested in Figs. 129 to 134 could be used with the three-phase system. The lighting load should be reasonably well balanced among the phases.

163. Three-phase, high-voltage distribution (Fig. 141) is used considerably for municipalities and is probably the best method for average

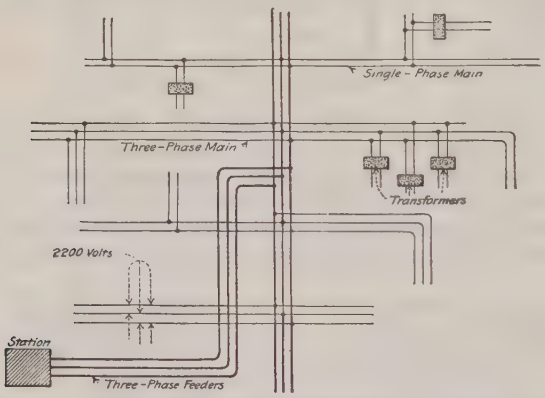


FIG. 141.—Three-phase feeder and mains in a municipality.

conditions. For three-wire, three-phase systems, 2,300 and 13,800 volts are employed. Developments are tending toward the use of the higher voltage. Where a four-wire, three-phase system is used the voltage between outer wires is, approximately, 4,160, but the voltage from any one of the outer wires to the neutral wire is 2,400, so standard transformers can be used. Single-phase transformers are used to serve the lighting loads. The transformers are so distributed on the three phases that the total load on the generator is approximately balanced. The secondaries of the lighting transformers are connected as are those of a system with single-phase primary conductors and may, as suggested in Fig. 136, be either two-wire or three-wire. All three wires of the three-phase circuit are not carried to all parts of the district served. Where the load is not dense, only two wires—giving a single-phase circuit—are used (see Fig. 141).

Motors exceeding 5 hp. in capacity should be at least 220 volt and three phase rather than single phase, and separate services should be

provided for motors exceeding 10 hp. in capacity. The methods of connecting transformers served by a three-phase system are given in the division on Transformers. It is best practice to provide individual feeders and mains for the motor and the lighting loads, but this cannot always be done. The three-phase, four-wire distribution system (Fig. 142) is used in several of the larger cities. Its advantage is that it saves copper, as the transmission voltage is 4,160 rather than 2,200. For further information see the division on Transformers.

164. Distribution-system Protection and Switches.—Distribution circuits are protected from ground and short-circuit currents by fuses or circuit breakers so arranged as to disconnect promptly the faulty circuit from its source of supply with the least possible interruption to other circuits. In order to accomplish this result the time lag for the different fuses and circuit breakers should be so coordinated that the unit nearest to the fault will operate first, the other units not operating at all.

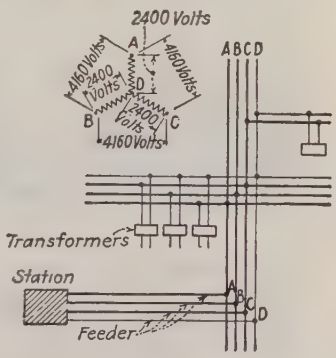
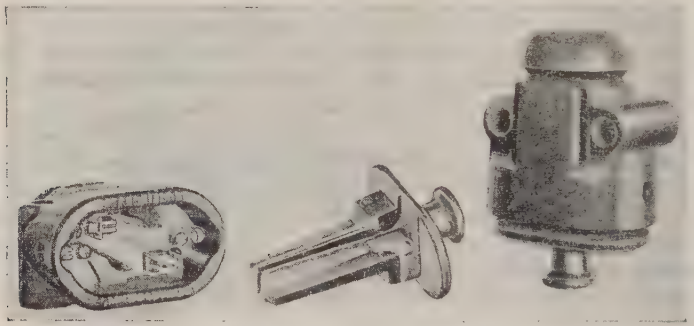


FIG. 142.—Three-phase four-wire distribution system.

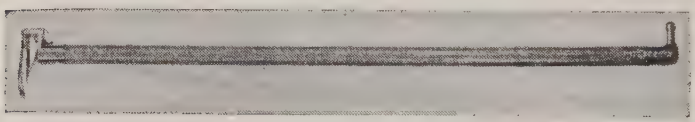
1. Services are protected inside the building by fuses or circuit breakers at the service entrance. These should have a relatively short time delay. On overhead systems, services are not protected at the supply end. On underground systems sometimes the services are protected by copper fuse links inside a junction box in the distribution box in the street where the taps are taken from the main. Where these are used their rating should be considerably above the rating of the service-switch fuses so that the junction-box links will blow only in the case of a short in the service cable itself.

2. Secondary mains on overhead systems or on radial underground systems are usually not protected, because fuses at that point make more trouble by blowing unnecessarily than the trouble they save. On underground ring or network systems, protection is afforded by circuit breakers and relays installed as a unit with the transformer feeding the main and called a network protector. The circuit breakers and relays are arranged to open in case of reverse power feeding back through the transformer from the main. Sometimes each section of the main is fused with a super-lag fuse link at the point where it joins another section, but the tendency is to get away from this practice on account of the difficulty in re-energizing a network after a general interruption of power due to a storm or flood. It is now considered better practice to let a short circuit on a main burn itself clear, which it will do in the majority of cases,

without interrupting service to the customers. The main can then be replaced later at the convenience of the power company and with the least interruption of service.



I-Base. II-Plug with link lines. III-Complete assembly.



IV-Safety plug puller.

FIG. 142A.—Insulator-type plug cutout. (*General Electric Co.*)

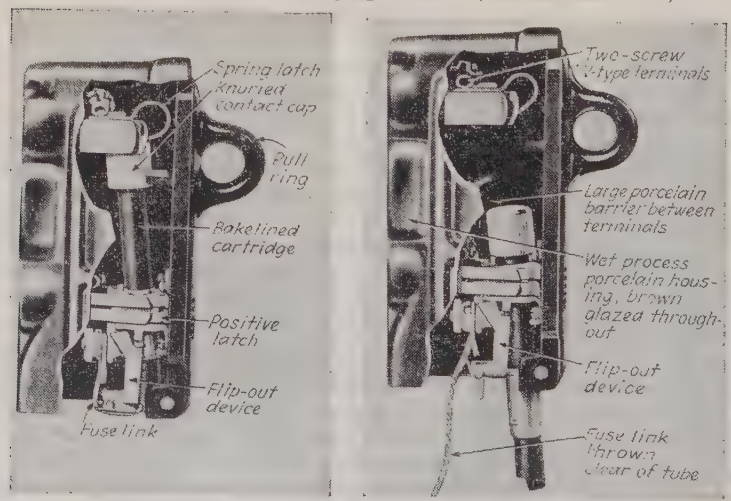
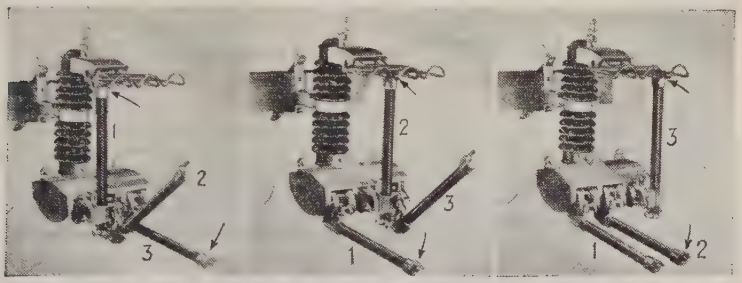


FIG. 143.—Dropout fuse cutout. (*Line Material Co.*)

3. Transformers on overhead radial systems are protected by fuses on the high-voltage side which have a rating of at least 200 per cent of the

transformer rating to avoid blowing on reasonable overloads. Sometimes proper fuse coordination will indicate an even larger rating than this. Although ordinary fuses enclosed in weatherproof porcelain cutouts have been used a great deal, the tendency is toward the use of



I-Fuse 1 in operating position. Fuse 2 in reserve position. Fuse 3 in secondary reserve.

II-Fuse 1 blown. Fuse 2 in operating position. Fuse 3 in reserve.

III-Fuse 2 cleared a second fault. Fuse 3 in operating position.

FIG. 144.—Reclosing fuses. (*James R. Kearney Corp.*)

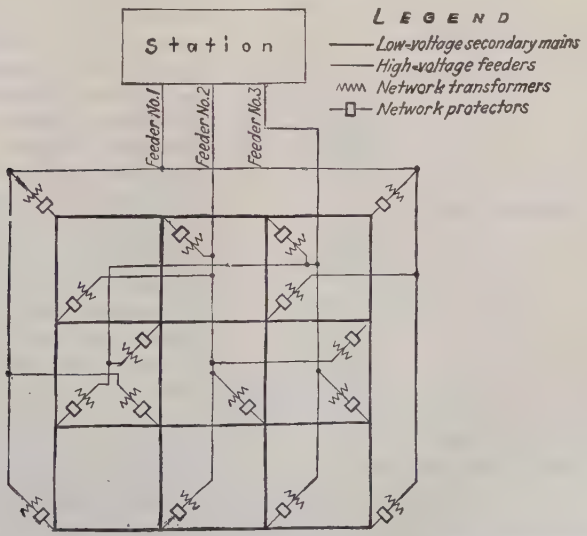
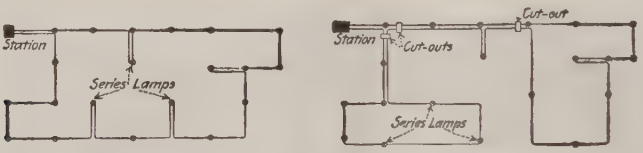


FIG. 145.—Automatic alternating-current network.

insulator type plug cutouts (Fig. 142*A*) with link fuses for the lower voltages and indicating drop-out fuses (Fig. 143) or reclosing fuses (Fig. 144) for the higher voltages. The indicating drop-out fuses facilitate the work of the service men in locating trouble, and the latter will provide

one or two reclosings of the circuit to take care of transient shorts due to wires or tree branches blowing in the wind. Typical installations are shown in Fig. 58. On underground network systems (Fig. 145) the automatic reclosing circuit breakers of the network protector protect the transformer.



I-Open loop series circuit. II-Mixed loop series circuit.

FIG. 146.—Series lighting circuits.

4. Primary feeders on overhead primary networks are protected by reclosing fuses or circuit breakers which reclose the circuit a few seconds after an interruption so as to restore power in those cases where the overload has cleared itself by other fuses blowing or by the cause of the short (such as tree branches) being removed. The breakers are arranged to lock out the circuit after one or two reclosings, in order to avoid unnecessary feeding into permanent short circuits.

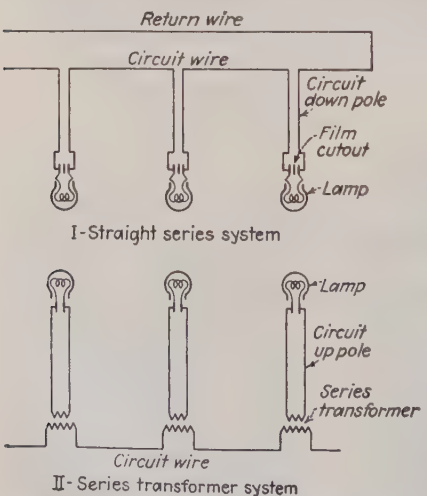


FIG. 147.—Circuits for series street lighting.

165. Series circuits (see Div. 3 for further information) are used for series-lighting and for fire-alarm and watchman's circuits.

166. In laying out a series circuit the open-loop system of distribution (Fig. 146, I) can be used if the circuit covers a relatively small area. If a large area is covered the system suggested in Fig. 146, II should be used because with it, if an open circuit occurs in some section, the section can be quickly isolated by throwing the cutout switch at the point where the section joins the main circuit. Series cutout switches, especially designed, can be purchased from electrical supply dealers. Obviously the open-loop plan requires a minimum of poles and wire; hence it is the most economical to install. When laying out series circuits, consideration should be given to future additions of lamps to the series circuit, and the circuit should be so routed that they can be included with the least

expense. The return wire of the circuit may be carried on the same poles with the wire which is connected to the lights, or it may return by a different route as illustrated by the different parts of Fig. 146. The circuit wire may be carried directly to the sockets of the lamps as shown in Fig. 147, I, or a series transformer may be used as in Fig. 147, II, and only the secondary circuit of the transformer carried to the lamp sockets. With the straight-series system, if a lamp burns out, the disk film cutout in the base of the lamp socket (see Div. 9) is punctured by the momentary high voltage which is produced when the circuit is interrupted by the burning out of the filament. The circuit is thus closed through the disk and the burned-out lamp shorted out of the circuit. The disadvantages of the straight-series system are that the lamp socket is subject to the high voltage of the circuit and the lamp current is limited to the one value of 6.6 amp. This system is the common one for overhead circuits, however. With the series-transformer system the circuit continuity is maintained through the primaries of the transformers irrespective of whether the lamps are burned out. The secondaries of the transformers operate at low voltage and may be obtained for either 6.6-, 7.5-, 15-, or 20 amp. values. This gives greater choice in the use of various sizes of lamps. Since the lamp circuit operates at low voltage, this type is frequently used with underground circuits. The transformer is placed in the base of the lamp standard, and the circuit up through the pole need not be insulated for high voltage.

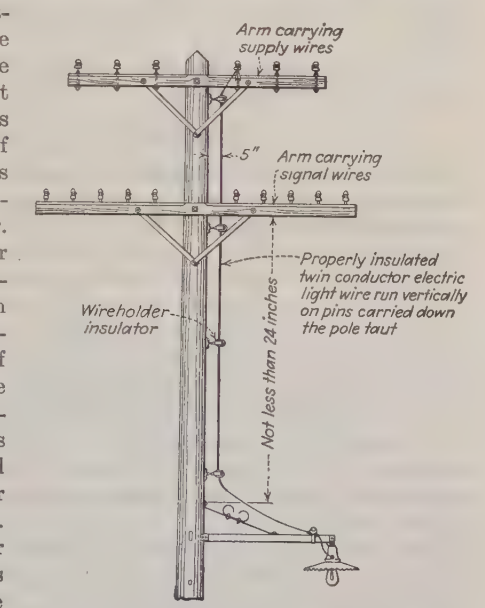


FIG. 148.—Method of running street-lighting circuit down the pole. (*Hubbard & Co.*)

167. Series Circuits on Pole Lines (From report of Committee on Overhead Line Construction, National Electric Light Association).—Every series circuit should start from station, substation, or other point of distribution, on a given pin and crossarm, and follow the same relative pin and crossarm throughout its course. Circuits should not jump from one location on a crossarm to another location on the same crossarm,

or to a different crossarm, but should always be placed on their proper pins. Such a system renders trouble hunting and repair work much simpler than they otherwise would be and is the only possible way in which circuits can be constructed, maintained, operated, and extended in a satisfactory systematic manner. As series incandescent circuits are cut dead during the daytime and will not, therefore, hamper linemen working on a pole, these circuits can often be run to advantage on the pole pins of the crossarm. Such an arrangement is also convenient for making lamp loop connections. As it is usual practice to ground all constant-current series circuits in the station, these wires should be considered as grounded by linemen when working on the poles, this in addition to the general rule that all wires should be treated as being alive at all times.

A common method of running a street-lighting circuit down a pole to the lamp is shown in Fig. 148.

GROUNDING OF SYSTEMS

168. Grounding of Distribution Circuits.—The National Electrical Code requires that on systems supplying interior wiring circuits one wire of the circuit shall be grounded, provided that the voltage from any other conductor to ground will not exceed 300 volts on d-c systems or 150 volts on a-c systems. Grounding helps to prevent accidents to persons and damage by fire to property in case of lightning, breakdown between primary and secondary windings of the transformers, or accidental contact between high-voltage wires and low-voltage wires. If some point on the low-voltage circuit is grounded:

1. Lightning striking the wires will be conducted into the ground.

2. Breakdown of the transformer insulation between primary and secondary coils will reveal itself through blowing of the primary transformer fuses if one wire of the primary circuit comes in contact with one of the secondary wires.

169. The value of grounding is illustrated in Fig. 149. One of the primary circuit wires is grounded at the transformer. The secondary is grounded at the customer's water pipe. An accidental cross between ungrounded primary and secondary wires is shown by the dotted line. Current will flow through the cross connection, the secondary of the transformer, the customer's water-pipe ground and up the ground connection to the other primary line. The voltage of the secondary wires to ground will be increased by the IZ drop through the water-pipe ground. A current of 100 amp. times a ground resistance of 2 ohms (there is practically no reactance) giving 200 volts would represent very severe conditions. This means that the secondary voltage to ground would be the normal 110 volts plus the 200 volts, giving 310 volts, which would probably not do any damage before the primary protective devices would open and break the circuit. This type of accidental cross should open

the substation-feeder circuit breaker. If the cross were in the transformer itself the primary fuse would open. If, however, there were no ground connection, the primary 2,300 volts would be impressed on the secondary system, which is insulated for only 250 to 600 volts, and numerous insulation breakdowns and considerable damage to equipment would occur. Also, there would be extreme danger to human life for anyone touching a fixture at such a time.

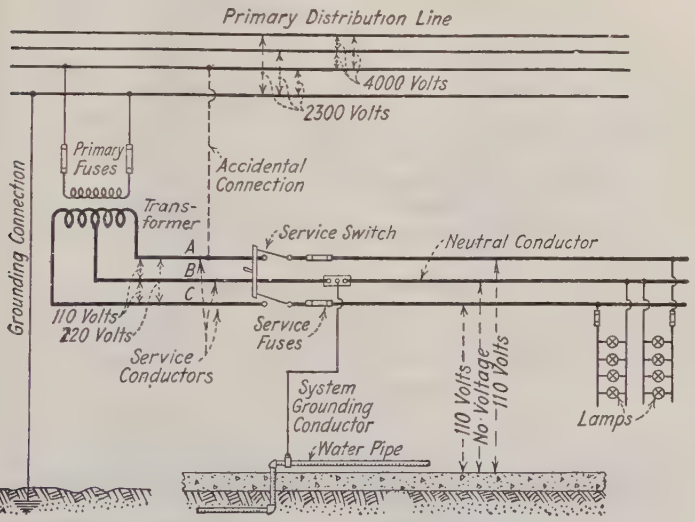


FIG. 149.—Ground connections for interior wiring systems.

170. High-voltage transmission systems are also frequently grounded in order to reduce the voltage to ground and consequently the line insulation required. For example, if a 220-kv., three-phase circuit has the windings of the supply transformer connected in Y, with the midpoint of the Y grounded, the voltage to ground will be $220 \div \sqrt{3} = 127$ kv. This reduction of the voltage to ground is of great value in insulating the transformer windings and in the number of insulators required for the line supports. At the same time, the advantage of the 220 kv. in reducing the line current and line losses is retained.

171. Ground-wire connections to transformer secondaries should be made to the neutral point or wire if one is accessible. Where no neutral point is accessible, one side of the secondary circuit may be grounded. Figure 150 shows theoretical diagrams of ground connections to transformer secondaries, and Fig. 151 illustrates how some of these connections are arranged with commercial transformers. The neutral point of each transformer feeding a two-phase, four-wire secondary should be grounded

unless the motors taking energy from the secondary have interconnected windings. Where they are interconnected, the center or neutral point of only one transformer is grounded. No primary windings are shown in Figs. 150 and 151. In Fig. 151 the secondary winding of each transformer is shown divided into two sections, as it is in commercial transformers.

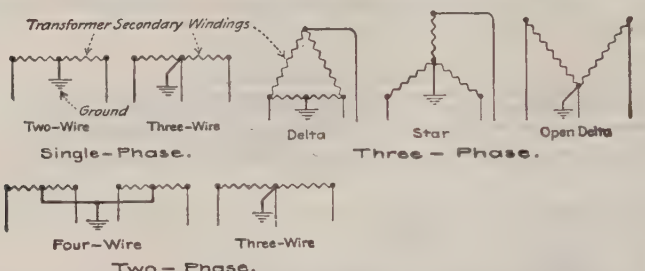


FIG. 150.—Theoretical diagrams of secondary ground connections.

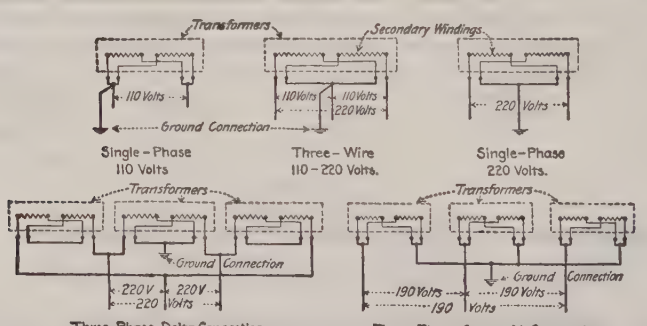


FIG. 151.—Ground connections to secondaries of commercial transformers.

172. Ground connections can be made in many ways. They may be made inside buildings by connecting to pipes or may be installed at the poles which support the transformers or the secondary networks. Central-station practice favors grounds at poles. Figures 152 and 153 show the method of making a pole ground used by the Allegheny County Light Company. The lower end of the pipe is pointed, the upper end is "tinned" inside, and the wooden plug is inserted in the upper end of the pipe in the Company's shop. In making a ground, the pipe is driven into the earth next to the pole, and the steel-cable ground conductor, its end having been tinned, is soldered into the upper end of the pipe by pouring molten solder in around it. An excellent feature of this method is that the $\frac{7}{16}$-in. ground conductor is so strong that it will never be disturbed. It is secured to the pole with pipe straps. (See Fig. 152.)

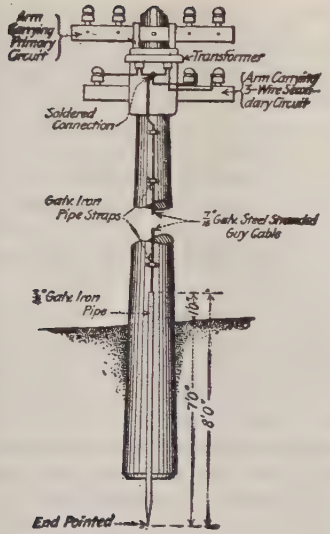


FIG. 152.—Method of grounding secondary circuit.

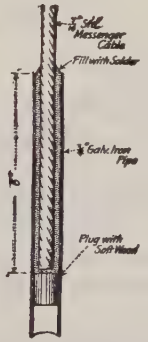


FIG. 153.—Method of connecting cable to pipe.

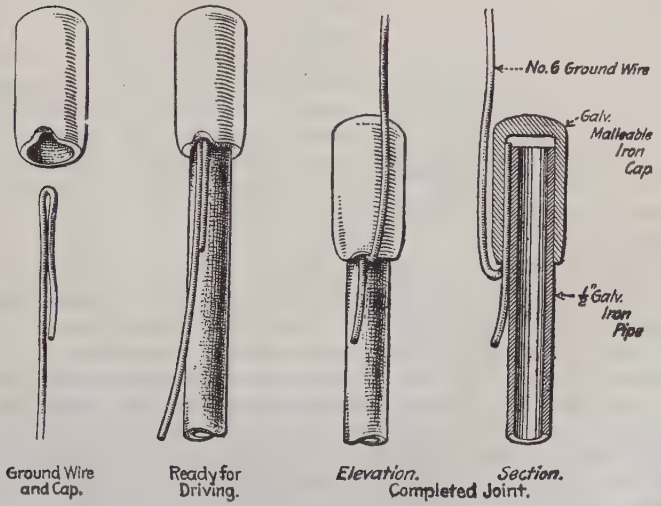


FIG. 154.—Making connection with ground-pipe cap.

The ground-pipe cap illustrated in Fig. 154 is used by several large central-station companies for connecting the ground wire to the ground pipe. Soldering is not necessary. The cap with the wire in position is placed over the top of the pipe and the pipe driven. In driving, the wire is firmly wedged between the cap and the pipe. The cap protects the top of the pipe. The cap fits ½-in. pipe or ¾-in. rod, with a No. 6 ground wire. Where No. 4 wire is used, it is not necessary to double it. Ground pipes must be long enough to reach permanently moist soil, and care must be taken in driving not to drive them into the pole and thereby insulate them.

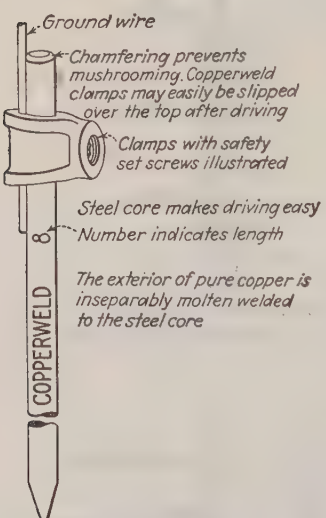


FIG. 155.—Ground rod and clamp. (*Copperweld Steel Co.*)

Ground rods made of steel pipe with copper-welded exterior surface (pointed at the bottom Fig. 155) are extensively used. The rod is driven into the ground, and the ground wire fastened by a clamp near the top of the rod. The copper coating provides for a good electrical connection and affords resistance to corrosion from the weather and earth.

173. Ground wires should be encased by wooden molding for a distance of at least 7 ft. from the surface, to protect against shocks to passersby. Under certain conditions of soil moisture, a shock can be received from a ground wire by a person standing on the earth's surface. The ground pipe extends about 1 ft. above ground and is not usually protected. Some companies encase the entire length of the ground wire in molding to protect the linemen.

No copper wire smaller than No. 6 should be used for a ground wire, and some companies use nothing smaller than No. 4. Copper wire is preferable. Bare wire is satisfactory and should be attached to the poles with cleats or straps. Staples, although used, should not be. The National Electrical Code requirements with respect to size of ground wires are given in Div. 9. There should be a ground for each transformer or group of transformers, and when transformers feed a network with a neutral wire, there should, in addition, be a ground at least every 500 ft. The National Electrical Safety Code specifies that all ground pipes shall be galvanized and have a minimum nominal diameter of ¾ in.

174. The National Electrical Safety Code requires that the ground resistance must be measured at the time of installing the ground, and

that the ground resistance must not exceed 3 ohms for water-pipe grounds and 25 ohms for driven grounds.

175. To measure the ground resistance, two additional temporary grounds, consisting of short rods 2 or 3 ft. long, must be driven in the

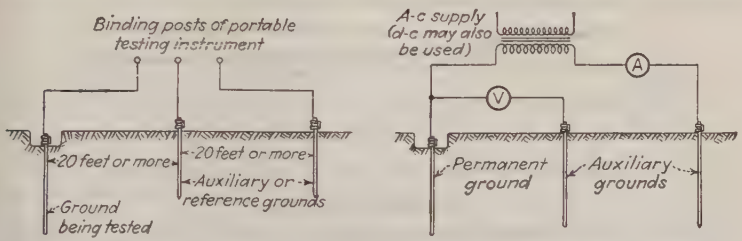


FIG. 156.—Circuits for measurement of ground resistance. (*Copperweld Steel Co.*)

ground at least 20 ft. away from the ground being tested (Fig. 156, I). A direct-reading instrument called a ground-ohmer or groundometer may then be connected to the three grounds by means of insulated leads. A magneto or a battery in the instrument furnishes the necessary power. The instrument reads the ground resistance directly in ohms. If a

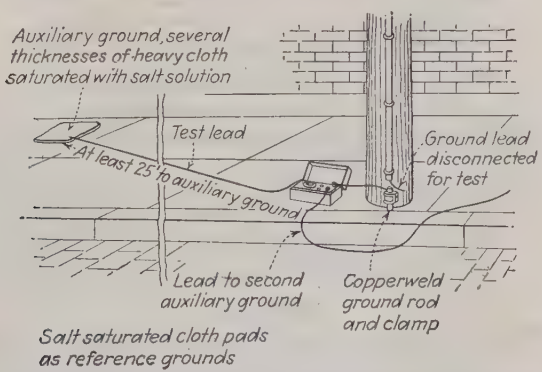


FIG. 157.—Testing ground resistances in paved streets.

source of direct or alternating current is available, the resistance may be measured by the fall-of-potential method with a voltmeter and ammeter, connections for which are shown in Fig. 156, II. The resistance is then calculated from $R_g = \frac{E}{I}$.

176. When testing ground resistance in city streets there may be no convenient place to drive the auxiliary grounds. In such a case a fire hydrant may be used for the auxiliary ground, or a pad made of several thicknesses of heavy cloth about 1 ft. square and saturated with salt water may be placed on the sidewalk (Fig. 157).

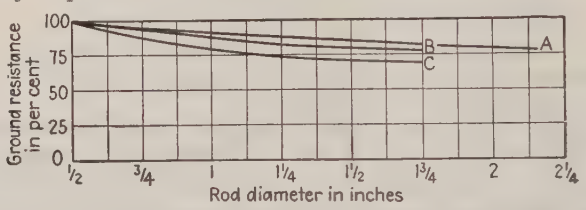


FIG. 158.—Effect of diameter of ground rod on ground resistance. (*Copperweld Steel Co.*)

177. Reduction of ground resistance in cases where it exceeds the allowable value of 25 ohms may be accomplished in several ways:

1. Use of a larger diameter ground rod.
2. Use of a longer ground rod.
3. Putting two, three, or more rods in parallel.
4. Chemical treatment of the soil.

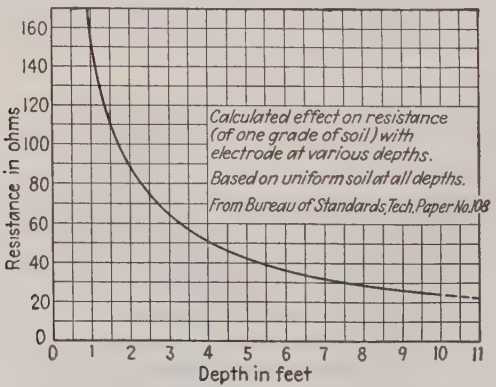


FIG. 159.—Effect of depth of ground rod on ground resistance. (*Copperweld Steel Co.*)

178. The effect of the use of a larger diameter rod is shown in Fig. 158. It will be noted that increasing the diameter of the ground rod does not effect much reduction in resistance, and use of ground rods larger than ¾ in. is not recommended. The diameter of the rod should be only large enough to permit it to be driven into the soil without bending.

179. Long ground rods made in sections coupled together are very effective where there is considerable depth of dry sand, and good moist soil is many feet underground. Although the 8-ft. minimum depth required by the National Electrical Code is sufficient for normal soil conditions, grounds as deep as 50 ft. have been used in very poor soil. The calculated effect of the depth of rod on ground resistance is shown in Fig. 159. The curve is for uniform soil at all depths. In practice the soil is always firmer and more moist the deeper the ground, so that the decrease of resistance with increase of depth is usually greater than is shown by the curve.

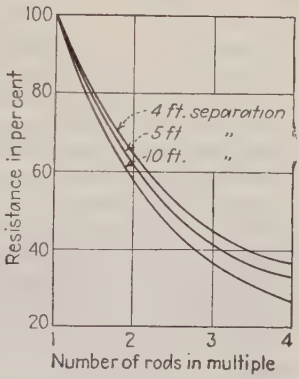


FIG. 160.—Effect on ground resistance of placing ground rods in multiple. (*Copperweld Steel Co.*)

180. Using several rods in multiple is a very effective means of lowering ground resistance as shown in Fig. 160. The recommended distance between rods is at least 6 ft., so that this method is more applicable to large steel-tower lines and substation structures than to wood-pole lines. Spacing rods as close together as the opposite sides of a wood pole is not recommended.

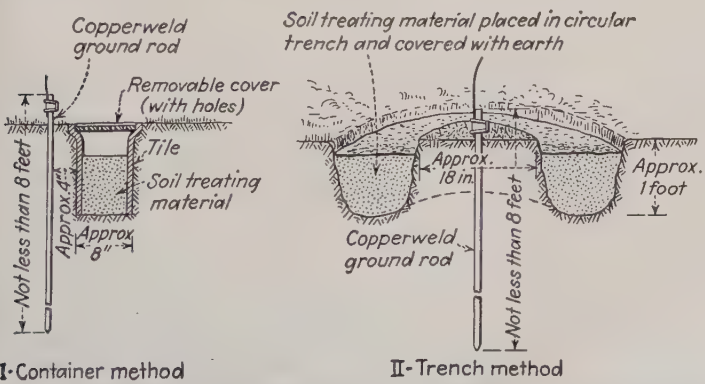


FIG. 161.—Methods of soil treatment for lowering of ground resistance. (*Copperweld Steel Co.*)

181. Chemical treatment of the soil is recommended for reducing ground resistance for those cases where the other methods of Secs. **179** and **180** are not practical.

There are two practical ways of accomplishing this result, as shown in Fig. 161. In the method of Fig. 161, I, a length of tile pipe is sunk in the ground a few inches from the ground rod and filled to within 1 ft. or so of the ground level with magnesium sulphate, copper sulphate, or common rock salt. The magnesium sulphate is the most common as it combines low cost with high electrical conductivity and low corrosive effect on the rod. This method is effective where there is limited space for soil treating, such as on city streets. The method of Fig. 161, II, is applicable where a circular or semicircular trench may be dug around the ground rod to hold the chemical. The chemical must be kept several inches away from direct contact with the ground rod to avoid corrosion of the rod. The first treatment requires 40 to 90 lb. of chemical and will retain its effectiveness for 2 to 3 years. Each replenishment of the chemical extends the effectiveness for a longer period so that future re-treating becomes less and less frequent. When the chemical is first installed, it is well to flood the treated area with water so that the chemical will diffuse through the soil. Thereafter normal rainfall will usually provide the necessary water for carrying the solution into the earth.

DIVISION 9

INTERIOR WIRING

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GENERAL

1. The National Electrical Code rules, which are the recommendations of the National Fire Protection Association, should be followed in installing all interior wiring. These rules are revised approximately every 2 or 3 years so it is inadvisable to include them in entirety in this book. A copy of these rules can be obtained by applying to any local fire inspection bureau or to the Underwriters' Laboratories, Chicago, Ill. All statements are made in accordance with the 1951 edition of the Code. The "National Electrical Code Handbook" by Arthur L. Abbott and published by the McGraw-Hill Book Co., Inc., gives the Code rules with illustrations and explanations of their application. The author's "Wiring for Light and Power," in addition to being a general treatise on the wiring of buildings, contains the National Electrical Code and many data in explanation thereof.

2. There are local regulations covering the installation of wiring, in force in many localities, which have been enacted by city or state governments. Sometimes these differ from the Code regulations so it is always well to be familiar with all the regulations in force before starting any work. The city and state rules are in reality laws and therefore take precedence over the National Electrical Code rules, which have no legal status.

3. Definitions (National Electrical Code).

(1) **Accessible:** (a) **As Applied to Wiring Methods:** Not permanently closed in by the structure or finish of the building; capable of being removed without disturbing the building structure or finish.

(b) **As Applied to Equipment:** Admitting close approach because not guarded by locked doors, elevation, or other effective means.

(2) **Appliance:** Appliances are current-consuming equipment, fixed or portable; for example, heating, cooking, and small motor-operated equipment.

(3) **Approved:** Acceptable to the authority enforcing the National Electrical Code.

(4) **Concealed:** Rendered inaccessible by the structure or finish of the building.

(5) **Connector, Pressure** (Solderless): A pressure connector is a connector in which contact between the conductor and the connector is obtained without the use of solder by means of mechanically applied pressure.

(6) **Exposed:** (a) **As Applied to Live Parts:** That a live part can be inadvertently touched or approached nearer than a safe distance by any person and is not suitably guarded or isolated.

(b) **As Applied to Wiring Methods:** Accessible; not concealed.

(7) **Fitting:** An accessory such as a lock nut, bushing, or other part of a wiring system which is intended primarily to perform a mechanical rather than an electrical function.

(8) **Guarded:** Covered, shielded, fenced, enclosed, or otherwise protected by means of suitable covers or casings, barriers, rails, or screens, mats or platforms, to remove the liability of dangerous contact or approach by persons or objects to a point of danger.

(9) **Isolated:** Not readily accessible to persons unless special means for access are used.

(10) **Dry Location:** A location not normally subject to dampness or wetness. A location classified as dry may be temporarily subject to dampness or wetness, as in the case of a building under construction.

(11) (a) **Damp Location:** A location subject to a moderate degree of moisture, such as some basements, some barns, some cold-storage warehouses, and the like.

(b) **Wet Location:** A location subject to saturation with water or other liquids, such as locations exposed to the weather, washrooms in garages, and like locations. Installations underground or in concrete slabs or masonry in direct contact with the earth shall be considered as wet locations.

(12) **Master Service:** The service conductor and service equipment supplying a group of buildings under one management.

(13) **Qualified Person:** One familiar with the construction and operation of the apparatus and the hazards involved.

(14) **Raceway:** Any channel for holding wires, cables, or bus bars, which is designed expressly for, and used solely for, this purpose.

(15) **Readily Accessible:** Capable of being reached quickly for operation, renewal, or inspection, without requiring those to whom ready access is requisite to climb over or remove obstacles or to resort to portable ladders, chairs, etc.

(16) **Special Permission:** The written consent of the authorities enforcing the Code.

4. Methods of Installing Interior Wiring.

1. Open wiring: on insulators.
2. Concealed knob and tube.
3. Rigid metal conduit.
4. Flexible metal conduit.
5. Liquid-tight flexible metal conduit.
6. Armored cable.
7. Surface metal raceways.
8. Electrical metallic tubing.
9. Nonmetallic-sheathed cable.
10. Service-entrance cable.
11. Nonmetallic surface extensions.
12. Nonmetallic waterproof wiring.
13. Underfloor raceways.
14. Underplaster extensions.
15. Wireways.
16. Bus ways.
17. Cellular-metal-floor raceways.
18. Bare-conductor feeders.
19. Multioutlet assemblies.

5. In the open-wiring method of installing interior wiring the wires are run exposed on the ceiling, roof structure, or walls. They are supported on porcelain insulators of either the knob (Figs. 167, Div. 4, and 168, Div. 4) or the cleat type (Figs. 171 and 172, Div. 4) so as to provide the necessary clearance between the wires and the surface wired over.

6. Concealed knob and tube wiring was one of the earliest methods of installing wiring. The wires were mounted on knobs and run through tubes where they pierced structural members of the building. They were then concealed by the wall and ceiling surface. This method is still allowed by the National Electrical Code, but the authors are strongly of the opinion that it is dangerous and should not be used on any new installation.

7. In the rigid-conduit method of installing interior wiring the wires are supported and protected from mechanical injury by being installed in special-grade iron pipe, called rigid conduit. The conduit may be run exposed, supported from the walls, ceilings, or roof structure, or it may be concealed in the partitions and floors. Provision for connection to the circuit at outlet and switch points is made by the insertion of sheet-steel boxes, cast-iron boxes, or special conduit fittings in the conduit run. The special conduit fittings are called by various trade names, such as condulets, unilets, or taplets. The conduit and outlet fittings or boxes are installed complete without the wires. After the conduit system is complete, the wires are pulled through from fitting to fitting.

8. The flexible-conduit method of installing interior wiring is similar to the rigid-conduit method except that a flexible steel conduit is employed instead of the rigid iron conduit. The runs of conduit with their boxes and fittings are installed first, and the wires are pulled in from box to box at a later date. Provisions for outlet connections are made by means of boxes inserted in the conduit runs.

8A. Liquid-tight flexible metal conduit is a special flexible conduit having an outer liquid-tight jacket. It is not intended for general wiring use. Wiring of this type may be used only for the connection of motors or portable equipment in wet locations where flexibility of connections is required. When used, it must be provided with suitable terminal fittings approved for the purpose. It cannot be used in sizes larger than $1\frac{1}{4}$ in. It shall not be used where subject to mechanical injury, where in contact with rapidly moving parts, where subjected to temperatures above 60°C. (140°F.), or in any hazardous location. See Table 25*A* in Div. 11 for maximum size of conductors allowed.

9. Armored cable consists of rubber-, thermoplastic-, or varnished-cambric-insulated wires protected from injury by a flexible steel armor. The wires and their armor are manufactured as a unit. The armored-cable method of installing wiring is somewhat similar to the flexible-

conduit method. In the flexible-conduit method the wires and the flexible conduit are entirely separate units, the conduit being installed first and the wires pulled in later, while with armored cable the wires and their flexible armor are installed as a unit. The wires cannot be removed from armored cable without destroying the armor. Provision for outlet and switch connections is made by the insertion of steel outlet or switch boxes in the cable runs.

10. In surface metal-raceway wiring the wires are supported in a thin sheet-steel casing. The raceway is installed exposed, being mounted on the walls or ceiling. The sheet-steel casing, called metal raceway or metal molding, is made with a flattened-oval or rectangular cross section. Most types of metal molding are made in two parts, a trough or base which is fastened to the wall or ceiling and a capping which is snapped on the base. After the base has been installed, the wires are laid in the trough formed by the base, and the capping is snapped on. One type of surface metal raceway, called Wiremold, is manufactured with the capping crimped on to the base at the factory. With this type the wires must be pulled through the raceway from outlet to outlet as in the conduit-wiring method. Provisions for outlet or switch connections are made by means of special fittings inserted in the runs of molding as required.

11. In the electrical-metallic-tubing method of installing wiring the wires are installed in a thin-walled metallic tube or thin-walled conduit, as it is sometimes called. Electrical metallic tubing is similar to rigid conduit except that it is constructed of much thinner material. Provisions for connecting outlets and switches to the circuit are made by means of special metallic-tubing fittings or by means of regular rigid-conduit fittings provided with an adapter. Electrical metallic tubing is made with both round and oval cross sections. After the tubing and fittings have been installed as a complete system, the wires are pulled in from fitting to fitting as in the rigid-conduit method.

12. Nonmetallic-sheathed cable consists of two or three rubber- or thermoplastic-insulated wires bound together and protected by a cotton-bound paper sheath and protected with an outer extra-heavy cotton braid, treated with a moisture- and heat-resisting compound. Nonmetallic cable may be run exposed on walls and ceilings or concealed in the hollow spaces between partitions or between floors and ceilings. The cable is fastened directly to the surface of the walls, ceilings, or structural members by means of metal straps. Provision for outlets and switches is made by running the cable into outlet boxes.

13. Service-entrance cable (see Div. 2) normally is used for the circuit from the point of attachment of the service conductors on the outside of the building to the service switch, load center, or meter cabinet just inside the building. It may, however, also be employed for the interior wiring on the load side of the service switch. It is not commonly

used for general interior wiring, but is used for certain special portions of the wiring such as to supply large appliances like an electric range, as a feeder to a distribution panel elsewhere in the building, or as a service cable to other buildings. For unrestricted use all the conductors must be rubber or thermoplastic insulated. If an uninsulated neutral is used the cable must have a final nonmetallic outer covering, the voltage to ground must not exceed 150 volts, and it may be used only to supply a range, domestic water-heater circuits (but not the heater itself), or, from a master service cabinet, to supply other buildings. The cable is fastened to the surface with straps spaced not over 4 ft. 6 in. apart.

14. A nonmetallic surface extension consists of a two-wire assembly fastened to the wood or plaster surface of the wall of a room. This system of wiring may be used in residential and office occupancies to supply additional convenience outlets in a room which already has at least one convenience outlet wired by some other approved system. The power supply must be from an approved fitting plugged into the existing outlet. Provision for the additional outlets is made by inserting special outlet fittings in the extension-cable assembly.

15. Nonmetallic waterproof wiring consists of multiconductor, rubber-insulated, rubber-sheathed cable supported on insulators mounted on the surface of walls, ceilings, or structural members. Provision for outlets is made by running the cable into special outlet fittings, which are provided with means for making a watertight connection to the cable. This method is used in exposed locations in breweries, ice plants, cold-storage warehouses, and similar wet locations where the wiring is subjected to mildly corrosive fumes and vapors and where the voltage does not exceed 150 volts to ground or 300 volts between conductors.

16. In the underfloor-raceway method of wiring the wires are installed in a sheet-metal or fiber casing, which is embedded in the concrete or cement fill of the floor. Generally, the ducts or raceways are laid out in the floor to form a network. Provision is made at the intersections of the ducts for the pulling in and splicing of wires by means of special floor junction boxes. Ducts of the sheet-metal type are provided with outlet openings spaced at regular intervals along the raceway. These outlet openings are either plugged or equipped with special floor-outlet fittings. With the fiber-duct type of raceway the raceway is first installed in the floor without any outlet openings. After the floor has been finished, outlets may be provided at any desired point along the duct runs by simply cutting a hole in the floor and duct and inserting a a special floor-outlet fitting. In the underfloor-raceway systems the wires are pulled through the ducts in the same manner as for rigid-conduit work.

17. Underplaster extensions are wiring systems laid in a channel cut in the plaster surface of a wall, down to the face of masonry or other wall material. Rigid or flexible metal conduit, armored cable, electrical

metallic tubing, or metal raceways approved for the purpose are laid in the channel and secured to the surface of the wall or ceiling structure. Provision for outlets is made by inserting shallow outlet boxes in the run of conduit, cable, tubing, or raceway. After the system has been secured in the channel, it is plastered over flush with the wall or ceiling surface.

18. In the wireway method of wiring the wires are supported and protected in a sheet-metal trough. The sheet-metal trough is installed exposed, being mounted on the ceiling or walls, or supported from the roof structure. One side of the trough is fitted with a sheet-metal hinged cover so that access may be had to the interior of the trough throughout its entire length. After the wireway has been installed as a complete system, the wires are laid in the trough, and the cover snapped shut. Mains and feeders are run in the wireways with taps for branches taken off at the most convenient point through rigid or flexible metal conduit, connected to the wireway through knockouts provided on the three sides of the trough. This system provides a flexible distribution system for industrial plants.

19. Bus-way systems of wiring consist of bare bus bars insulated from each other and supported and protected by a sheet-steel housing. The housing and bus bars are assembled as a unit at the factory in 10-ft. sections. The system is installed by supporting the housing from the ceiling, walls, or roof structure. Bus-way systems are extensively used for the feeder and main circuits in industrial plants. They are available in three general types: without provision for outlets, with provision for fixed outlets, and with provision for continuously movable outlets for portable tools and electric-welding work. With the type which has provision for fixed outlets, openings are provided every few inches for branch taps. The connection of a tap to the bus bars is accomplished through the insertion of a special power attachment plug in these openings. For the wiring of the branch circuit from the power plug to the apparatus to be supplied with power, flexible conduit, rigid conduit, or armored cable may be employed. This method of wiring provides a very flexible system which meets in an economical manner the requirements of plants where production conditions necessitate the frequent shifting or replacement of machinery.

20. In the cellular-metal-floor-raceway wiring, the floor is constructed of special metal structural members containing hollow spaces or cells which form raceways for the wires. Provision for pulling in and splicing wires is made by means of locating special junction boxes in the floor between sections of the floor members. Outlet openings and fittings may be originally provided at regular intervals along the raceway formed by the cells, or outlets may be provided at any time after completion of the buliding construction by simply cutting a hole in the floor and cell wall and inserting a special floor-outlet fitting. After the complete floor

structure has been erected and finished over, the wires are pulled through the raceway formed by the floor cell structure and the junction boxes.

21. Bare-conductor feeders are allowed only by special permission. When allowed, such a feeder installation consists of bare conductors supported on noncombustible, nonabsorptive insulating supports and enclosed in a chase, channel, or shaft of noncombustible material.

22. Multioutlet assemblies are a special form of surface metal raceway with built-in single receptacle outlets, every few inches. The assembly is supported on the surface of walls or in or on top of baseboards. It is used for convenience-outlet wiring in dwellings and commercial buildings for providing very convenient and adequate convenience outlets. The assembly is supplied with power through an armored cable or conduit run concealed in the walls and brought into the back of the assembly.

23. Applications of Different Wiring Methods

Method of wiring	Applications allowed by National Electrical Code		
	Type of location allowed in	Max. size of wire allowed and max. allowable voltage	General field of application
Open wiring, exposed on insulators	Any location except in hoistways, hazardous locations, commercial garages, theaters, or motion-picture studios	No restrictions on wire, 600 volts	For motor feeders and mains in buildings of mill-type construction; for installations where the cost of installation must be kept as low as possible and appearance is of little consequence. Prohibited by many local codes for residential and commercial occupancies
Rigid conduit	Any installation either concealed or exposed	No restrictions on wire or voltage	Best but most expensive method; used in practically all buildings of fireproof construction, and in mill-type construction for lighting and motor branch circuits
Flexible conduit	Any installation either concealed or exposed, except that it should not be embedded in concrete floors and walls or employed in hazardous locations or in storage-battery rooms or in hoistways except for connection to limit switches, push buttons, and similar devices	No restrictions on wire, 600 volts	Principal use is for extensions to or in conjunction with rigid-conduit systems where cramped wiring space makes it difficult or impossible to install rigid conduit; also for concealed wiring in frame buildings

Applications of Different Wiring Methods (*Continued*)

Method of wiring	Applications allowed by National Electrical Code		
	Type of location allowed in	Max. size of wire allowed and max. allowable voltage	General field of application
Armored cable	Any dry, nonhazardous location either exposed or concealed; may be run in grooves in brick or tile walls and concealed in plaster finish; for damp locations must have lead sheath under armor	No restrictions on wire, 600 volts	Used principally for wiring residences, small office buildings, and stores
Surface metal raceways, multioutlet assemblies	Only in exposed, dry, and nonhazardous locations; cannot be used where it will be subject to severe mechanical injury or corrosive vapors	No. 6 wire, 600 volts if metal is 0.04 in. thick, otherwise 300 volts	Additions to existing installations and in installations where the layout of the circuits is subject to frequent change; for convenience outlets along baseboards
Electrical metallic tubing	May be used either exposed or concealed in dry locations; may be buried in concrete, other than cinder concrete, or in masonry walls if provided with watertight fittings. Cannot be used where it will be subject to severe mechanical injury either during installation or afterward or to corrosive vapors unless made of corrosion-resistant material suitable for the conditions	No restrictions on wire, 600 volts	Additions to existing installations and in installations where the layout of the circuits is subject to frequent change
Nonmetallic-sheathed cable	May be installed either exposed or concealed in continuously dry locations; cannot be installed in masonry, concrete, or fill or be buried in plaster	No restrictions on wire size, 600 volts	Used for low-cost installations in residences and small store and office buildings; used for extensions to existing systems
Service-entrance cable: (*a*) All wires insulated	Services; interior wiring	No restrictions on wire size, 600 volts	Services to residences and small stores; circuits to heavy-duty outlets in residences and small stores
(*b*) Covered-neutral type	From service drop to meter, to range, to domestic water heater, to other buildings	No restrictions on wire size, 150 volts to ground	Services to residences and small stores where in a protected location

Applications of Different Wiring Methods (*Continued*)

Method of wiring	Applications allowed by National Electrical Code		
	Type of location allowed in	Max. size of wire allowed and max. allowable voltage	General field of application
(*c*) Armored	Any	No restrictions	Same as (*a*) but where location is not protected
Nonmetallic surface extensions	Residential or office, exposed dry locations inside single room for supplying convenience outlets. Not where subject to corrosive vapors	Not stated but No. 10 is max. practical size, 150 volts	For houses and offices to supply additional convenience outlets where it is difficult to conceal wiring
Nonmetallic waterproof	Exposed wet and mildly corrosive vapor locations	No. 12 min. wire, no max. wire size; 150 volts to ground, 300 volts between conductors	Breweries, ice plants, cold-storage warehouses and other wet locations
Underfloor raceways	May be installed in buildings of fireproof construction in dry locations free from corrosive or hazardous conditions	No 4. wire, 600 volts	Used principally in office buildings to provide telephone and signal outlets and outlets for electrical office machines
Underplaster extensions	Buildings of fire-resistive construction, on face of masonry, buried in plaster finish	No wire restrictions but practical only for small sizes, 600 volts	For rewiring where circuits cannot be fished from outlet to outlet
Wireways	May be installed exposed in dry locations in garages, theaters, and industrial buildings, cannot be used in hoistways or where they will be subject to severe mechanical injury or corrosive vapors	500,000-cir. mil wire, 600 volts	Used for the distribution of power in industrial buildings where the machines are subject to frequent rearrangement; in theaters where there are a large number of conductors in one run
Bus ways	Exposed dry, nonhazardous locations where not subject to mechanical injury or corrosive vapors	No restrictions on size of bus (wires are not used), 600 volts	Used for feeders, mains, and risers in industrial and office buildings
Cellular-metal-floor raceways	Residential and office occupancies	No. 0 wire, 600 volts	For office buildings and better class residences to provide a flexible system for power and signal outlets
Bare-conductor feeders	Buildings of fire-resistive construction in channel or shaft, dry location not subject to corrosive vapors	No restrictions on wire size, 600 volts	For feeders for large office buildings

Applications of Different Wiring Methods (*Continued*)

Method of wiring	Applications allowed by National Electrical Code		
	Type of location allowed in	Max. size of wire allowed and max. allowable voltage	General field of application
Liquid-tight flexible metal conduit	Only for connection of motors and portable equipment	No. 2 wire, 600 volts. Max. size conduit 1¼ in.	Not for general use. To be used only for motors and portable equipment in wet locations where flexibility of connection is required

24. Approved Types of Conductor Insulations

Insulation	Type letter	Max. operating temp.		Applications allowed										
		Deg. C.	Deg. F.	Open wiring on insulators	Concealed knob and tube	Rigid metal conduit	Flexible metal conduit	Surface metal raceways	Electrical metallic tubing	Underfloor raceways	Cellular-metal-floor raceways	Wireways	Switchboards
Code-grade rubber	R	60	140	√	√	√	√	√	√	√	√	√	√
Heat-resistant rubber	RH	75	167	√	√	√	√	√	√	√	√	√	√
Moisture-resistant rubber	RW	60	140	√	√	√	√	√	√	√	√	√	
Thermoplastic waterproof	TW	60	140	√	√	√	√	√	√	√	√	√	
Latex (regular)	RU	60	140	√	√	√	√	√	√	√	√	√	
Latex (moisture-resistant)	RUW	60	140	√	√	√	√	√	√	√	√	√	
Thermoplastic	T	60	140	√	√	√	√	√	√	√	√	√	√
Varnished cambric	V	85	185	√[a]	√[a]	√[a]	√[a]	...	√[a]	√[a]	√[a]	√[a]	√
Asbestos varnished cambric	AVA	110	230	√[a]	√[a]	√[a]	√[a]	...	√[a]	√[a]	√[a]	√[a]	√
Asbestos varnished cambric	AVB	90	194	√[a]	√[a]	√[a]	√[a]	...	√[a]	√[a]	√[a]	√[a]	√
Asbestos varnished cambric	AVL	110	230	...	...	√	√	...	√	√	√		
Thermoplastic asbestos	TA	90	194	...	...	...	...	...	...	...	...	...	√
Asbestos	A	200	392	√[a]									
Asbestos	AA	200	392	√[a]									
Impregnated asbestos	AI	125	257	√[a]									
Asbestos	AIA	125	257	√[a]									
Paper	....	85	185	...	...	√[b]							
Slow-burning	SB	90	194	√[c]		√[e]	√[e]	√[e]	√[e]	√[e]	√[e]	√[e]	√[e]
Slow-burning weatherproof	SBW	90	194	√[c]									
Weatherproof	WP	80	176	√[d]									

[a] Dry locations only.
[b] Lead-covered, underground. Elsewhere by special permission.
[c] Dry location where ambient temperature exceeds 85°C. For corrosive-vapor locations.
[d] By special permission only.
[e] Where temperatures will exceed those allowed for rubber or varnished cambric.

25. Approved Locations for Various Wiring Methods

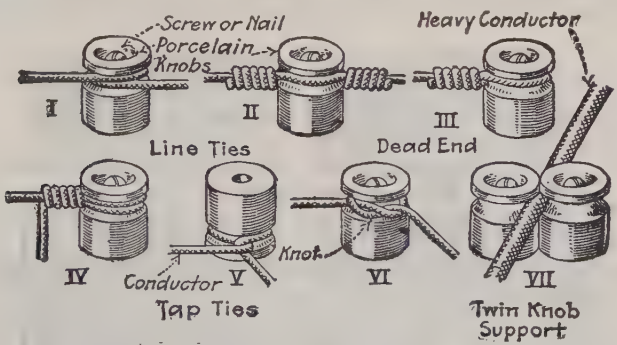
Types of wiring	Approved locations																		
	Exterior of buildings																		
	When readily accessible and within 8 ft. of ground	Not readily accessible, over 8 ft. from ground	Where liable to contact with moving objects	Concealed dry locations	Exposed dry locations	Concealed wet locations	Exposed wet locations	Hoistways	Elevator cars	Sign wiring	Over 600 volts	Hollow spaces in walls and ceilings	Embedded in masonry or concrete	Embedded in plaster finish	Hazardous locations	Storage-battery rooms	Corrosive-vapor locations	Breweries, ice-houses, and wet locations
Open wiring on insulators	...	✓	..	..	✓	..	✓	..	..	✓	..	..	...	..	..	✓	✓	✓
Concealed knob and tube	...	...	..	✓	..	✓	..	..	..	..	..	✓	...	..	..	..	✓	
Rigid metal conduit	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓[a]	✓	✓
Flexible metal conduit	...	...	..	✓	✓	✓[b]	✓[b]	✓[c]	✓	✓	..	✓	✓[b]	✓	..	.	✓	✓[b]
Armored cable	✓[d]	✓[d]	..	✓	✓	✓[d]	✓[d]	✓[c]	✓	✓	..	✓	✓[d]	✓	..	....	✓	✓[d]
Surface metal raceways	...	...	..	..	✓	...	...	...	..	..	..	..	...	✓				
Electrical metallic tubing	✓	✓	✓	✓	✓	✓	✓	...	✓	✓	..	✓	✓	✓	..	...	..	✓
Nonmetallic-sheathed cable	...	...	..	✓	✓	...	...	...	..	..	..	✓						
Service-entrance cable	✓	✓	✓	✓	✓	...	✓	...	..	..	..	✓	...		..	.	✓	
Nonmetallic surface extensions	...	...	..	..	✓[e]			..	..	..	..	..						
Nonmetallic waterproof wiring	...	...	..	..	..	...	✓	...	..	..	..	..	...	..	..	..	✓	✓
Underfloor raceways	...	...	..	✓	..	...	...	...	..	..	..	..	✓					
Cellular-metal-floor raceways	...	...	..	✓	..	✓	...	...	..	..	..	✓						
Underplaster extensions	...	...	..	✓	..	..	...	...	..	..	..	..	..	✓	..	..	✓	
Wireways	...	...	..	..	✓	...	...	...	✓	✓	..	..						
Busways	...	...	..	..	✓													
Bare-conductor feeders	...	...	..	..	..	...	...	...	..	..	..	✓						
Multioutlet assemblies	...[f]	...	..	..	✓													

[a] Noncorrodible type.
[b] With lead-covered conductors.
[c] For limit switch, interlocks, and push buttons only.
[d] Lead-covered type.
[e] Except basements and attics.

OPEN WIRING ON INSULATORS

26. Open wiring on insulators is one of the cheapest methods of installing wiring. It finds wide application for temporary installations and in factories and mills for the installation of feeder circuits in some places where appearance is of little consequence. It is also used for running feeders in tunnels and in specially built feeder shafts in fireproof buildings. The wires may be rubber, thermoplastic, varnished-cambric, asbestos, or a slow-burning or slow-burning-weatherproof insulation. Slow-burning, varnished-cambric, or asbestos wire cannot be used in cellars, basements, under roofs, or in other places exposed to moisture. The wires must be supported at least every 4½ ft., except in mill buildings, where a support on each beam may be approved for wires No. 8 and larger if they are separated at least 6 in. The wires must, in dry places, be separated ½ in. from the surface wired over and spaced 2½ in. apart for voltages up to 300. Above 300 volts and up to 600 volts, the wires must be separated from the surface wired over by at least 1 in. and must be spaced 4 in. apart. In wet places, wires must be at least 1 in. from surface wired over, for all voltages.

27. Knobs and Methods of Supporting Conductors on Them.—Knobs for supporting conductors in interior work are of porcelain. Split knobs



NOTE.—Methods of tying shown at I, V, and VI are not approved by the Code and should not be used except in temporary installations not subject to inspection. They should never be used in permanent work.

FIG. 1.—Methods of attaching to knobs.

or cleats must be used for supporting conductors smaller than No. 8 Brown and Sharpe gage. Some methods of securing wires to knobs are shown in Fig. 1. The line tie of I is made by winding the conductor once around the knob, so both ends of the wire must be under tension to hold the wire in position. A tie wire is used as II. In making up the tie wire the slack can be drawn out of the conductor. A dead end or

termination is shown at III. Where it is necessary to change the direction of a run to get the conductor to an outlet or for any other reason tap ties IV, V, and VI are used. It is not practicable to tie large conductors, so they may be supported as at VII.

For a discussion of types of knobs see Div. 4.

28. Tie wires must have an insulation equal to that of the conductors they confine and may be used in connection with solid knobs for the support of wires of size No. 8 or larger.

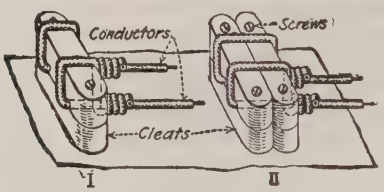


Fig. 2.—Dead-ending on cleats.

29. The method of dead ending on a cleat at the end of a run is illustrated in Fig. 2. After the wire is passed through the groove the free end is given several short turns around the line. Where a long run is dead-ended it is often advisable to fasten two sets of cleats in such a way that one bears against the other so that both will assume the strain as shown at II. For types and dimensions of cleats see Div. 4.

30. Methods of Terminating Heavy Conductors.—At the ends of all important open-wire runs of wires larger than, say, No. 8, strain insulators engaging in some wire-tightening device should be used. Figure 3

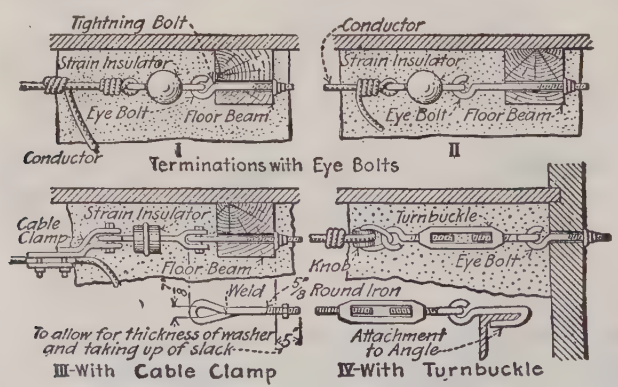


Fig. 3.—Methods of terminating conductors.

illustrates some methods. Either tightening bolts or turnbuckles can be used. The insulator may be of the type extensively used in trolley-line construction as in I, II, and III, or it may be a heavy knob (IV) held to the tightening device with stout wire. Where a run changes direction a cable clamp (see Index for a further description) can often be used with economy, particularly with large conductors. Where a cable clamp is

used, it is unnecessary to cut the conductor to change its direction, and the necessity of making up turns about the line wire as in I and II is eliminated.

31. The different approved methods of exposed surface wiring as arranged in a building of mill construction are illustrated in Fig. 4.

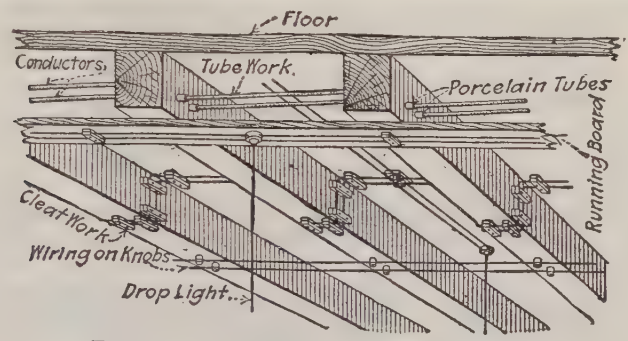


FIG. 4.—Open-work wiring in a mill building.

Which method should be used in any particular case is a matter that is largely determined by the size of the wire involved and other local conditions.

32. Mechanical Protection of Exposed Surface Wiring.—The wires must be protected on side walls from mechanical injury and, when

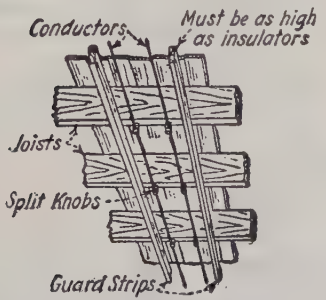


FIG. 5.—Guard strips to protect open wiring crossing ceiling joists.

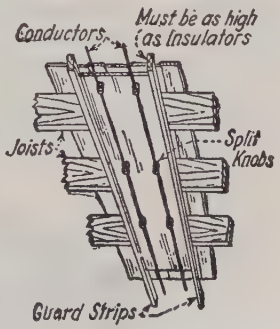


FIG. 6.—Running board with guard strips to protect open wiring crossing ceiling joists.

crossing floor timbers in cellars or in rooms where they might be disturbed, must be protected by guard strips or running board and guard strips as shown in Figs. 5 and 6. The guard strips must be at least

⅞ in. thick and at least as high as the insulators. Where a running board is used, it must be at least ½ in. thick and must extend at least 1 in. outside the conductors but not more than 2 in. The wires should also be protected by porcelain tubes when passing over pipes (Fig. 7) or any other members.

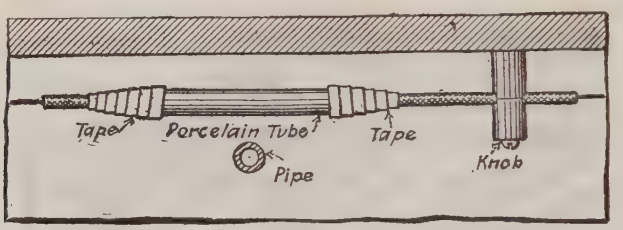


FIG. 7.—Protection of conductor passing over pipe.

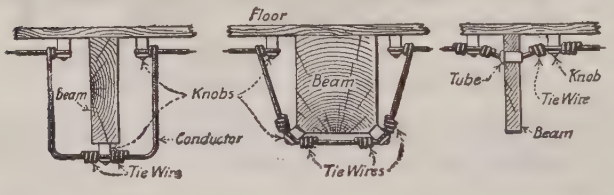


FIG. 8.—Open work wiring with knobs.

33. Methods of carrying exposed wiring around and through beams are illustrated in Fig. 4, which shows the tube-and-cleat arrangements. In Fig. 8 are shown some methods that can be used when wires are supported on knobs.

34. In steel mill buildings heavy conductors may be carried on the lower chords of the roof trusses (Fig. 9). This is a good location as the

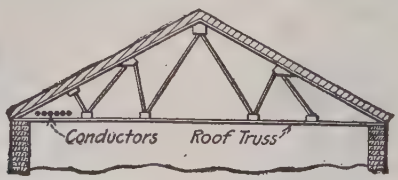


FIG. 9.—Conductors carried on roof truss.

conductors are out of the way and not apt to be disturbed. At each truss the conductors can be supported by one of the methods illustrated in Fig. 10. With the method of Fig. 10, I, the conductor merely rests in the insulator, and the entire longitudinal strain is taken by strain insulators attached to tightening bolts or turnbuckles at the ends of the run.

This method has the disadvantage that if the conductor breaks at any point or is burnt in two it will fall to the floor. The tie-wire method of II is seldom used, though it is satisfactory if cleats are not obtainable. (Split knobs or cleats must be used for conductors smaller than No. 8.) The cleat and through-bolt method of III is probably the best, all things considered. After the conductor has been drawn taut with the tighten-

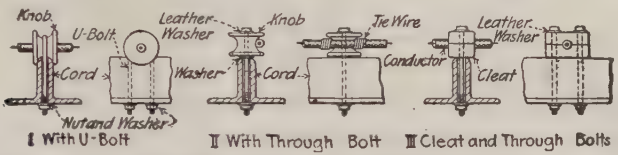


Fig. 10.—Attaching knobs to truss chords.

ing bolts at the ends of the run the cleat bolts are tightened, and each cleat then assumes its share of the stress. Tie wires, which are unreliable and may cut into the insulation of the conductor, are unnecessary. Leather washers should be used between the insulator and bolt to prevent breakage.

35. For supporting conductors on steel angles the Universal Insulator Support (Figs. 11 and 12 and Table 36) is a convenient fitting. It is of

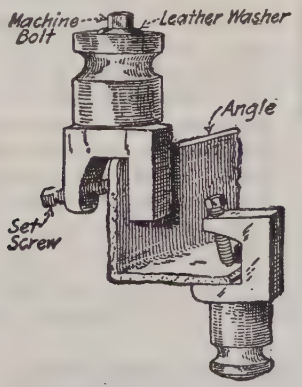


Fig. 11.

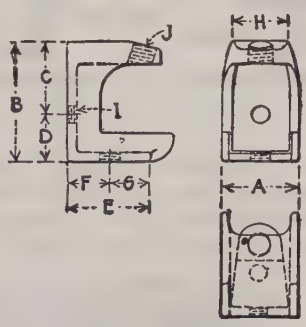


Fig. 12.

Fig. 11.—Universal Insulator Supports on an angle. (Note that split knobs must be used where conductors smaller than No. 8 are to be supported.)
Fig. 12.—The Universal Insulator Support.

malleable iron and can be clamped on the flanges of steel beams, angles, channels, Z bars, and on round, square, and flat bars. It can also be attached to gas and water pipes and to the edges of plates and tanks. Two insulators can be fastened to each support when necessary. Cup-pointed, casehardened set-screws are used. Leather washers should be used under the bolts that hold the insulators.

36. Dimensions of Universal Insulator Supports
(Steel City Electric Co., Pittsburgh, Pa.)

A, size, in.	For insulators, Nos.	*B*, in.	*C*, in.	*D*, in.	*E*, in.	*F*, in.	*G*, in.	*H*, in.	*I*, diam. of tapped hole	*J*, diam. of set-screw furnished
1	5, 5½	1½	⅞	⅝	1 1/16	9/16	½	¾	¼	5/16
1½	10, 4, 4½	1¾	1¾	⅝	1½	9/16	¾	¾	5/16	7/16
2	1, 3, 3 W.G., 3½, 24	2	1	1	2	1	1	¾	⅜	½
2½	25, 29, 34	2½	1¼	1¼	2½	1¼	1¼	¾	½	⅝

37. For supporting conductors on steel columns a wooden baseboard for the cleats clamped to the column with hook bolts (Fig. 13) is a good arrangement. The board must be cut out in back for the riveteads in the column. Strap-iron cleats through which the hook bolts pass prevent warping and splitting.

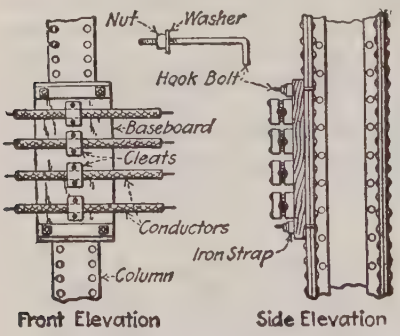


FIG. 13.—Attachment of wiring board to column.

38. Wire racks are used to support conductors, principally heavy ones, where there are many conductors in the run. The conductors should have flameproof or slow-burning covering. A wire rack can be made of wood fashioned into a framework somewhat along the lines of the steel ones of Figs. 14 and 15. The cleats insulating the conductors are held to the frame with wood screws or, preferably, with machine or stove bolts. A commercial wire rack with a cast-iron base that can be bolted to any surface is shown in Fig. 16. Generally a steel-

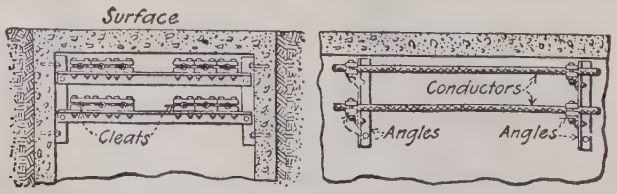


FIG. 14.—Angle-iron rack for conductors.

frame rack is preferable to a wooden one. The rack of steel angles of Fig. 14 was designed for installation in the top of a pipe tunnel. The insulators are held to the cross angles with bolts with a leather washer under the head

of each. The structural-steel rack of Fig. 15, III is arranged for supporting from a ceiling. Angle crossarms can be used as at II, or the crossarms

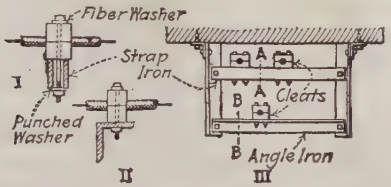


FIG. 15.—Rack composed of angles and strap iron.

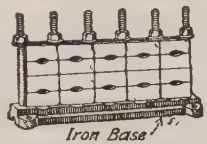


FIG. 16.—A commercial insulator rack.

can each be formed of two iron straps as at I. With the two-strap method, drilling for the cleat bolts is unnecessary, and the cleats can be shifted along the arm into any desired position and there clamped fast. Strain insulators engaging in turnbuckles or tightening bolts should be used at the ends of each straight run to assume the strain and to provide for tightening, or else the arms and cleats at the run ends should be reinforced to assume the stress that will come on them.

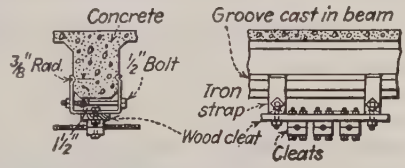


FIG. 17.—Supports for open wiring on a concrete beam.

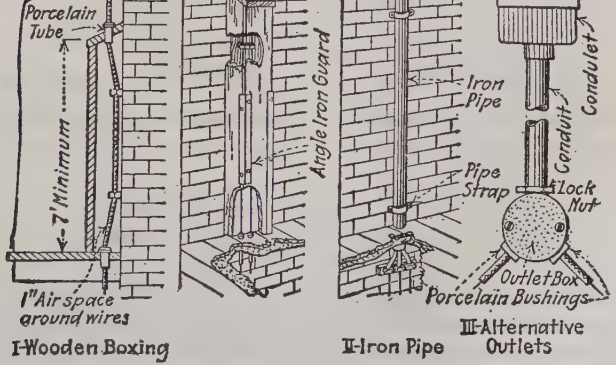


FIG. 18.—Protection of conductors on side walls.

39 A method of supporting open wiring in concrete buildings is shown in Fig. 17. A round groove of 3/8-in. radius is cast in the faces of

the beams, by having ¾-in., half-round molding nailed in the forms. Wrought-iron yokes are bent to fit the grooves as shown, and ½-in. bolts clamp them in position. Wooden blocks or sections of strap or angle iron can be bolted to the yokes for supporting the wire cleats.

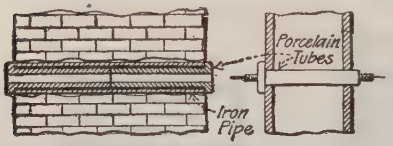


FIG. 19.—Protection through walls and partitions.

40. Suitable protection on side walls should extend not less than 7 ft. from the floor (Fig. 18). This may consist of substantial boxing, providing an air space of 1 in. around the conductors, closed at the top (the wire passing through porcelain-bushed holes) or a conduit with condulets on each end providing individual bushed holes for each wire (Fig. 18, II).

41. Where conductors pass through floors, walls, or partitions, they must always be protected. Open-work wires can be protected with porcelain tubes (Fig. 19). The tube or bushing must be long enough to bush the entire length of the hole in one continuous piece, or else the hole must first be bushed by a continuous waterproof tube. This tube may be a conductor, such as iron pipe, but in that case an insulating bushing must be pushed into each end of it, extending far enough to keep the wire absolutely out of contact with the pipe.

42. A tube for protecting a wire where it crosses another wire should always be so placed that the tube will not force the unprotected wire

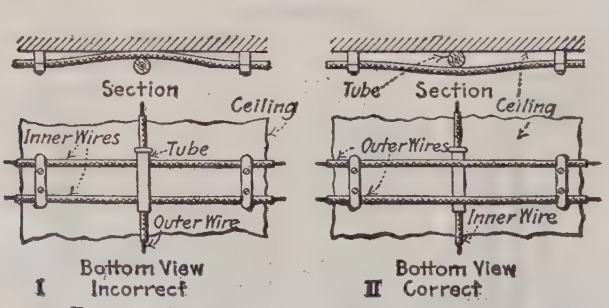


FIG. 20.—Methods of placing protecting tubes.

against the surface supporting the conductors. The tube should always be on the inner wire (Fig. 20). If placed on the outer wire, the tube may force the unprotected wire against the surface as shown in Fig. 20, I.

43. Flexible tubing or "loom" (Fig. 21) is used mostly in connection with open wiring and concealed knob and tube wiring. It finds application in mixed wiring, where short sections of rigid conduit are installed,

being used as additional insulation and protection for the entire length of conductor within the rigid conduit. When metal outlet boxes or switch boxes are used, flexible tubing is required from the last porcelain support, extending into the outlet box at least 1 in. and held in place by an approved fitting such as a universal bushing or a clamp. It need not be fastened securely into a wooden cabinet, but a porcelain bushing such as a federal bushing is generally used to keep out dust and make a tight fit. Another application for flexible tubing is in buildings already completed where the wires are fished in between the walls and ceilings. The tubing is used as a covering on such wires separately encased. In concealed knob and tube work it is frequently impracticable to place wires 3 in. apart and 1 in. from the surface wired over as required by the National Electrical Code, and in such cases the wires must be separately encased in flexible tubing. In open wiring where the amount of separation required by the Code from the surface wired over cannot be maintained, the wires may also be encased in flexible tubing.

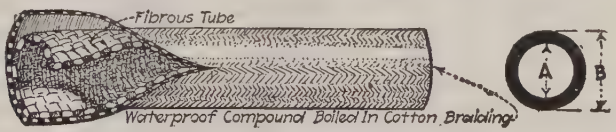


Fig. 21.—Flexible tubing.

The following is a list of places where flexible tubing is applicable: in open work where wires are exposed nearer each other than 2½ in.; on wires crossing other wires; on wires crossing gas pipes, water pipes, iron beams, woodwork, brick, or stone; on wires at chandeliers and bracket outlets; on gas pipe back of insulating joints; on wires under the edges of canopies; and at distributing centers or where space is limited and the 3-in. separation required cannot be maintained, each wire must be separately encased in a continuous length of flexible tubing. In many other places flexible tubing is employed as an added protection to wires; as, for instance, on portable wires around machinery where it is apt to become saturated with oil, and in show windows, etc., where added protection although not required is often desirable.

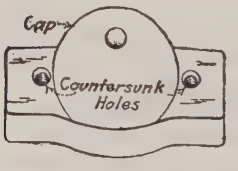
It is also used at the backs of switchboards to cover conductors where they emerge from conduit, or where the conductors pass through walls, etc. It must be used on the loop system and be continuous from outlet to outlet. It must not be installed in damp places or in any way subject to moisture (such as being placed in contact with damp mortar, plaster, etc). Duplex wires are not permitted in flexible tubing, although single-braided conductors are allowed.

Only continuous lengths of flexible tubing can be used for wire protection at outlets.

44. Properties of Flexible Tubing or Loom

A, inside diam., in.	B, outside diam., in.		Ft. per coil	Largest wire, B. & S. or cir. mils	Weight, lb. per 1,000 ft.
	In decimals	To nearest 64 in.			
7/32	0.46	15/32	250	No. 14	50
1/4	0.50	1/2	250	No. 14	58
3/8	0.65	21/32	250	No. 12	75
1/2	0.78	25/32	200	No. 8	90
5/8	0.98	63/64	200	No. 4	120
3/4	1.06	1 1/16	150	No. 2	196
1	1.31	1 5/16	100	No. 2/0	250
1 1/4	1.63	1 41/64	100	200,000	400
1 1/2	1.88	1 57/64	Odd lengths	400,000	480
1 3/4	2.25	2 1/4	Odd lengths	600,000	590
2	2.63	2 41/64	Odd lengths	800,000	800
2 1/4	2.81	2 13/16	Odd lengths	1,100,000	810

45. Where conductors cross damp pipes they should be carried over rather than under, so that drippings will not strike the wires. Porcelain tubes, securely taped to the conductors, should be placed on the conductors over the point where they cross.



46. Rosettes for open surface wiring are used to connect the drop cords for the incandescent lamps to the branch circuits. A rosette with protected (concealed) contact lugs is preferable to one with exposed lugs. Figure 22 shows one good type. Another good method of supporting drop cords, particularly where there is vibration, is with the ceiling button illustrated in Fig. 23.

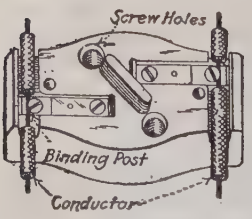


FIG. 22.—A cleat rosette.

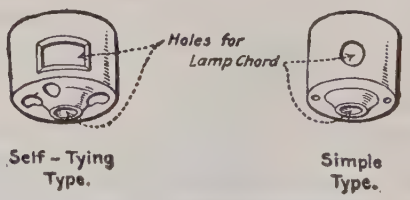


FIG. 23.—Ceiling buttons.

47. Switches can be supported in exposed surface wiring as shown in Fig. 24. The switch can be mounted on a commercial porcelain switch block.

48. Sockets for damp places should be of porcelain and hard rubber, or composition weatherproof, or, as they are sometimes called, "water-proof" (Fig. 25). Unless made up on fixtures they should be hung by separate-stranded, rubber-insulated wires, not smaller than No. 14 Brown and Sharpe gage, which should preferably be twisted together when the pendant is over 3 ft. long. The leads furnished in weatherproof sockets are 6 or 8 in. long, but longer ones can be supplied on special order. The socket leads must be soldered direct to the circuit wires but supported independently of them. Figure 26 shows a short drop, and Fig. 27 a long one; both figures illustrate the method of using cleats to remove the stress from the line conductors. Waterproof sockets are always keyless. Porcelain sockets are easily broken; hence, although their use is not formally approved by the Underwriters, brass-shell sockets thoroughly taped and coated with waterproof paint are sometimes used. Where not apt to be broken, porcelain sockets are the best.

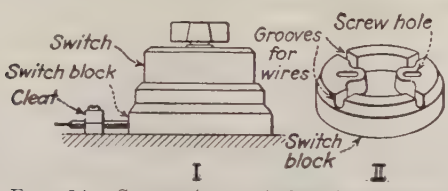


FIG. 24.—Supporting switches in exposed surface wiring.

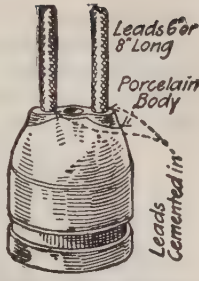


FIG. 25.—Weatherproof socket.

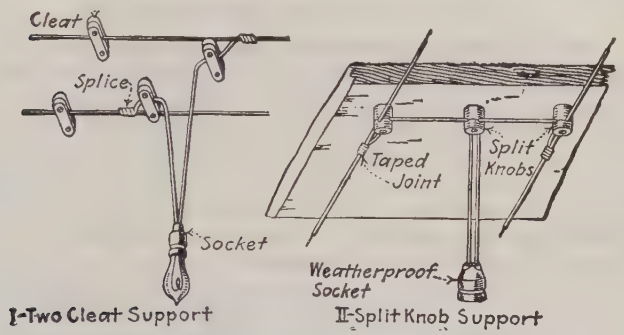


FIG. 26.—Short weatherproof pendant.

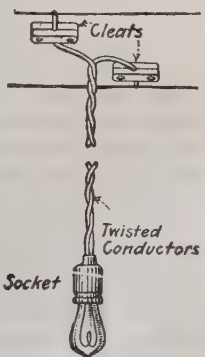


FIG. 27.—Long weatherproof pendant.

49. Receptacles for damp places are shown in Fig. 28. They are especially designed to withstand moisture but should always be supported on porcelain knobs. The rubber-insulated leads extend 6 or 8 in. from the body. The leads must be soldered directly to the line wires, and the joint must be well taped.

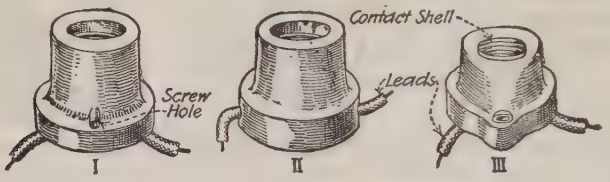


FIG. 28.—Receptacles for damp places.

50. Wiring troughs are sometimes used in damp places (Fig. 29). The troughs protect the conductors from drippings but not from water that condenses on them out of the atmosphere. In assembling wiring troughs, abutting edges should be coated with tar or with a thick waterproof paint. Screws smeared with paint should be used to hold the pieces together, and the screw heads should be painted. A wiring trough in addition to keeping drippings from the conductors constitutes a mechanical protection for the conductors. The wiring trough serves the same purpose as a running board in this respect.

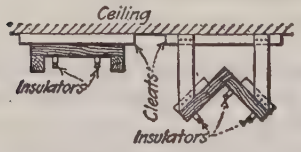


FIG. 29.—Wiring troughs.

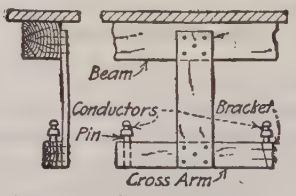


FIG. 30.—Crossarm support.

51. Porcelain or glass petticoat insulators probably form the best support for wiring in damp places. These are the same insulators that are used on outdoor pole lines. There is apt to be considerable electrical leakage in damp places with ordinary knobs and cleats, and the long creepage distance provided by petticoat insulators constitutes good protection against this. The insulators are supported on thoroughly painted wooden pins or brackets, which are held by small crossarms (Fig. 30). In no case should the insulator be mounted upside down. Glass or porcelain knobs, mounted on a small crossarm, are sometimes used instead of insulators but are not so good from an insulation standpoint. The advantage of mounting them on the arm is that an ample separation from the surface wired over is thus provided. The crossarm and support should be thoroughly painted with a waterproof paint or tar.

52. Joints and splices in damp places must be soldered with great care and should be thoroughly taped. A thorough painting of the tape wrapping with a waterproof compound, asphalt, or tar will protect against the entrance of moisture. Splices should be avoided in damp places, but, where necessary, they should be located at some distance from a point of support, because the insulation resistance of the insulation around a splice is less than that of an equal length of perfect wire.

53. Entering Damp or Wet Locations (National Electrical Code).—Conductors entering or leaving damp or wet locations shall have drip loops formed on them and shall then pass upward and inward from the outside of buildings, or from the damp or wet location, through noncombustible, nonabsorptive tubes.

CONCEALED KNOB AND TUBE WIRING

54. Concealed knob and tube wiring was used extensively at one time for the wiring of frame buildings where a low-cost installation was essential. It is still allowed by the National Electrical Code but is prohibited by most city codes. It has been superseded for low-cost installations by the nonmetallic-sheathed cable.

55. Thermal Insulation in Walls (National Electrical Code).—If thermal insulation is used in the hollow spaces of walls and ceilings in which concealed knob and tube work is installed, only approved noncorrosive, noncombustible, nonconducting thermal-insulation materials shall be used, and these shall be applied in a manner not liable to place a strain upon the conductors or supports.

56. When changing from open wiring or concealed knob and tube wiring to conduit, electrical-metallic-tubing, nonmetallic-sheathed-cable, armored-cable, or surface-metal-raceway wiring, a fitting or outlet box having a separately bushed hole for each conductor must be used.

RIGID-METAL-CONDUIT WIRING

57. Rigid-metal-conduit wiring is approved for both exposed and concealed work and for use in nearly all classes of buildings. For ordinary conditions, wiring in metal conduit is probably the best, although it is the most expensive. The advantages of metal conduit are (1) it is fireproof, (2) it is moistureproof, (3) it is strong enough mechanically so that nails cannot be driven through it and so that it is not readily deformed by blows or by wheelbarrows being run over it, and (4) it successfully resists the normal action of cement when embedded in partitions or walls of fireproof buildings.

58. When to Use Rigid-metal-conduit Wiring.—In general, conduit wiring should be used whenever the job will stand the cost. Ordinances of some cities now require that all concealed wiring shall be in metal conduit. It is probable that the method will, because of its inherent advantages, grow in popularity and will ultimately be almost universally

used. Rigid conduit protects the conductors it contains and provides a smooth raceway permitting ready insertion or removal.

59. When conduit is used in cinder fill it must be located at least 18 in. under the fill or be protected on all sides by a layer of non-cinder concrete at least 2 in. thick, or the conduit must be of corrosion-resistant material suitable for the purpose.

60. Iron conduit is made in two types: white (galvanized) and black (enameled). The white conduit is galvanized and is the type which should be used where exposed to the weather, when embedded in concrete, or when installed in continuously damp places. The black conduit is coated with black enamel and is the type commonly used for general interior wiring.

61. Standard Rigid Conduit and Couplings

Conduit

FIG. 31.—Section of conduit.

Couplings

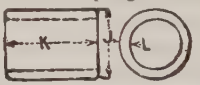


FIG. 32.—Conduit couplings.

Nominal size, in.	*A*, actual outside diam., in.	*B*, inside diam., in.	*C*, thickness of walls, in.	Nominal weight, lb. per ft.	Internal area, sq. in.	*J*, outside diam., in.	*K*, length, in.	*L*, thickness, in.	Weight of 100, lb.
½	0.84	0.623	0.109	0.85	0.304	1 3/32	1 5/16	¼	15½
¾	1.05	0.824	0.113	1.12	0.533	1 11/32	1 9/16	1 9/64	25½
1	1.315	1.048	0.134	1.67	0.864	1 21/32	1¾	1 11/32	40½
1¼	1.66	1.380	0.140	2.24	1.495	2	1 15/16	1 13/32	57½
1½	1.90	1.611	0.145	2.68	2.036	2 9/32	2 3/16	⅜	71¼
2	2.375	2.067	0.154	3.61	3.355	2 27/32	2 5/16	1 5/32	132
2½	2.875	2.468	0.204	5.94	4.788	3 9/32	2 11/16	1 7/32	185
3	3.50	3.067	0.217	7.54	7.393	4 1/64	3	3 3/64	300
3½	4.00	3.548	0.226	9.00	9.886	4½	3⅜	½	400
4	4.50	4.026	0.237	10.66	12.730	5 3/32	3⅜	½	412

All tubes 10 ft. long, threaded both ends, with coupling on one end.

62. Data on conduit couplings and elbows are given in Secs. **61** and **67**. The weight columns are convenient for estimating transportation charges. The internal area is useful in determining the size of conduit for unusual combinations of conductors, as explained in Sec. **73**. Dimensions of elbows and couplings are often used in laying out work on the drawing

board or in cases where clearances must be estimated in advance. Table 63 gives the dimensions of standard conduit threads.

63. Standard Conduit and Pipe Threads

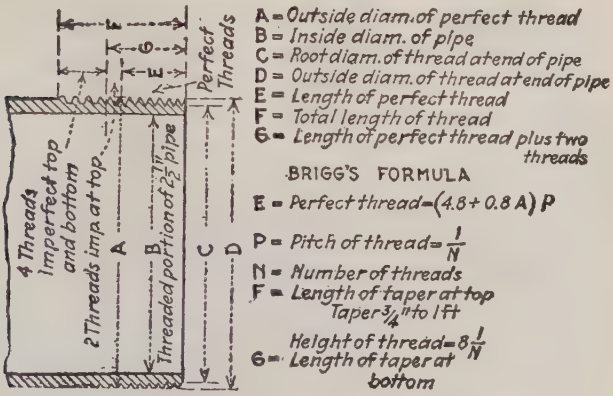


FIG. 33.—Standard conduit and pipe threads.

Size, pipe	No. of threads per in.	A	B	C	D	E	F	G	Diam. drill, in.
⅛	27	0.405	0.270	0.334	0.393	0.19	0.41	0.264	21/64
¼	18	0.540	0.364	0.433	0.522	0.29	0.62	0.402	7/16
⅜	18	0.675	0.494	0.567	0.656	0.30	0.63	0.408	9/16
½	14	0.840	0.623	0.702	0.816	0.39	0.82	0.534	11/16
¾	14	1.050	0.824	0.911	1.025	0.40	0.83	0.546	29/32
1	11½	1.315	1.048	1.144	1.283	0.51	1.03	0.683	1 5/32
1¼	11½	1.660	1.380	1.488	1.627	0.53	1.06	0.707	1 15/32
1½	11½	1.900	1.611	1.727	1.866	0.55	1.07	0.724	1 23/32
2	11½	2.375	2.067	2.200	2.339	0.58	1.10	0.757	2 7/32
2½	8	2.875	2.468	2.618	2.818	0.89	1.64	1.138	2 5/8
3	8	3.500	3.067	3.243	3.443	0.95	1.70	1.200	3¼
3½	8	4.000	3.548	3.738	3.938	1.00	1.75	1.250	3 23/64
4	8	4.500	4.026	4.233	4.443	1.05	1.80	1.300	4¼

64. Table 68 of conduit-bushing dimensions gives values which are helpful when laying out conduit holes in outlets or panel boxes. Clearances can be provided and holes can be so disposed that the bushings will have ample turning room. The dimensions in the table were taken from samples.

65. Spacings for Conduit with Given Clearances and Punched-steel Conduit Lock Nuts

(All dimensions in inches)

The *Clearance, C,* values are based on the *D* values given at the top of the next page.

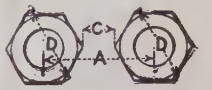


FIG. 34.—End view.

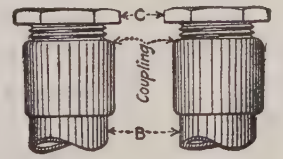


FIG. 35.—Elevation.

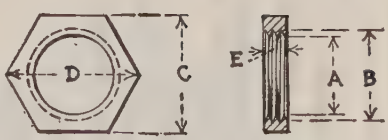


FIG. 36.—Conduit lock nut.

Spacings

Size conduit		C = ¼ in.							
½	A	1 3/8	1 1/2	1 5/8	1 13/16	1 15/16	2 1/4	2 5/16	2 7/8
	B	0.53	0.55	0.54	0.55	0.56	0.64	0.70	0.70
¾	A	1 1/2	1 5/8	1 3/4	1 15/16	2 1/16	2 3/8	2 11/16	3
	B	0.55	0.57	0.56	0.58	0.58	0.66	0.72	0.72
1	A	1 3/8	1 3/4	1 7/8	2 1/16	2 3/16	2 1/2	2 13/16	3 1/8
	B	0.55	0.57	0.56	0.58	0.58	0.66	0.72	0.72
1¼	A	1 13/16	1 15/16	2 1/16	2 1/4	2 3/8	2 11/16	3	3 3/8
	B	0.55	0.58	0.58	0.58	0.59	0.67	0.73	0.79
1½	A	1 15/16	2 1/16	2 3/16	2 3/8	2 1/2	2 13/16	3 1/8	3 1/2
	B	0.56	0.58	0.58	0.59	0.59	0.68	0.74	0.79
2	A	2 1/4	2 3/8	2 1/2	2 11/16	2 13/16	3 1/8	3 7/16	3 3/4
	B	0.64	0.66	0.65	0.67	0.68	0.75	0.81	0.81
2½	A	2 9/16	2 11/16	2 13/16	3	3 1/8	3 7/16	3 3/4	4 1/16
	B	0.70	0.72	0.72	0.73	0.74	0.81	0.87	0.88
3	A	2 7/8	3	3 1/8	3 3/8	3 1/2	3 3/4	4 1/16	4 3/16
	B	0.70	0.72	0.72	0.79	0.79	0.81	0.88	1.06
3½	A	3 1/4	3 3/8	3 1/2	3 11/16	3 13/16	4 1/8	4 7/16	4 7/8
	B	0.83	0.86	0.85	0.86	0.87	0.94	1.00	1.12

Size conduit		C = 3/8 in.							
½	A	1 1/2	1 5/8	1 3/4	1 15/16	2 1/16	2 3/8	2 11/16	3
	B	0.66	0.68	0.67	0.68	0.69	0.77	0.83	0.83
¾	A	1 5/8	1 3/4	1 7/8	2 1/16	2 3/16	2 1/2	2 13/16	3 1/8
	B	0.68	0.70	0.69	0.71	0.71	0.79	0.85	0.85
1	A	1 3/4	1 7/8	2	2 3/16	2 5/16	2 5/8	2 15/16	3 1/4
	B	0.68	0.69	0.69	0.71	0.71	0.78	0.85	0.85
1¼	A	1 15/16	2 1/16	2 3/16	2 3/8	2 1/2	2 3/16	3 1/8	3 1/2
	B	0.68	0.71	0.71	0.71	0.72	0.80	0.87	0.92
1½	A	2 1/16	2 3/16	2 5/16	2 1/2	2 5/8	2 15/16	3 1/4	3 3/8
	B	0.69	0.71	0.71	0.72	0.72	0.81	0.87	0.92
2	A	2 3/8	2 1/2	2 5/8	2 13/16	2 15/16	3 1/4	3 7/16	3 7/8
	B	0.77	0.79	0.78	0.80	0.81	0.88	0.88	0.94
2½	A	2 11/16	2 13/16	2 15/16	3 1/8	3 1/4	3 9/16	3 7/8	4 3/16
	B	0.83	0.85	0.85	0.86	0.87	0.94	1.01	1.01
3	A	3	3 1/8	3 1/4	3 1/2	3 5/8	3 7/8	4 3/16	4 1 1/16
	B	0.83	0.85	0.85	0.92	0.92	0.94	0.99	0.99
3½	A	3 3/8	3 1/2	3 5/8	3 13/16	3 15/16	4 1/4	4 9/16	5
	B	0.96	0.98	0.98	0.99	0.99	1.07	1.13	1.25

Locknut dimensions

Nominal size of conduit, in.	Threads per in.	A, in.
½	14	0.701
¾	14	0 911
1	11½	1.144
1¼	11½	1.488
1½	11½	1.727
2	11½	2.223
2½	8	2.620
3[a]	8	3 241

[a] The 3-inch lock nut is octagonal instead of hexagonal

Nominal size of conduit, in.	B, in.	C, in.
		oct. hex.
½	0.815	1-1 1/16
¾	1.025	1 1/4
1	1.283	1 1/2
1¼	1.627	2 1/32
1½	1.866	2 1/4
2	2 339	2 23/32
2½	2.820	3 1/4
3	3.441	4 11/32–3 11/16

Size conduit		$C = \frac{1}{2}$ in.							
		½	¾	1	1¼	1½	2	2½	3
½	A	1⅝	1¾	1⅞	2 1/16	2 3/16	2½	2 13/16	3 1/8
	B	0.78	0.80	0.79	0.80	0.81	0.89	0.95	0.95
¾	A	1¾	1⅞	2	2 3/16	2 5/16	2⅝	2 15/16	3¼
	B	0.80	0.82	0.81	0.83	0.83	0.91	0.97	0.97
1	A	1⅞	2	2⅛	2 5/16	2 7/16	2¾	3 1/16	3⅜
	B	0.80	0.81	0.81	0.83	0.83	0.90	0.97	0.97
1¼	A	2 1/16	2 3/16	2 5/16	2½	2⅝	2 15/16	3¼	3⅝
	B	0.80	0.83	0.83	0.83	0.84	0.92	0.99	1.04
1½	A	2 3/16	2 5/16	2 7/16	2⅝	2¾	3 1/16	3⅜	3¾
	B	0.81	0.83	0.83	0.84	0.84	0.93	0.98	1.04
2	A	2½	2⅝	2¾	2 15/16	3 1/16	3⅜	3 11/16	4
	B	0.89	0.91	0.90	0.92	0.93	1.00	1.00	1.06
2½	A	2 13/16	2 15/16	3 1/16	3¼	3⅜	3 11/16	4	4 5/16
	B	0.95	0.97	0.97	0.98	0.09	1.06	1.13	1.13
3	A	3⅛	3¼	3⅜	3⅝	3¾	4	4 5/16	4 13/16
	B	0.95	0.97	0.97	1.04	1.04	1.06	1.14	1.14
3½	A	3½	3⅝	3¾	3 15/16	4 1/16	4⅛	4 11/16	5 5/16
	B	1.01	1.04	1.03	1.04	1.11	1.13	1.31	1.31

Size conduit		$C = \frac{3}{8}$ in.							
		½	¾	1	1¼	1½	2	2½	3
½	A	1¾	1⅞	2	2 3/16	2 5/16	2⅝	2 15/16	3¼
	B	0.91	0.93	0.92	0.93	0.94	1.02	1.08	1.08
¾	A	1⅞	2	2⅛	2 3/16	2 7/16	2¾	3 1/16	3⅜
	B	0.93	0.95	0.94	0.96	0.96	1.04	1.10	1.10
1	A	2	2⅛	2¼	2 7/16	2 9/16	2⅞	3 3/16	3½
	B	0.92	0.94	0.94	0.96	0.96	1.03	1.10	1.10
1¼	A	2 3/16	2 5/16	2 7/16	2⅝	2¾	3 1/16	3⅜	3¾
	B	0.93	0.96	0.96	0.96	0.96	0.97	1.05	1.12
1½	A	2 5/16	2 7/16	2 9/16	2¾	2⅞	3 3/16	3½	4
	B	0.94	0.96	0.96	0.97	0.97	1.06	1.11	1.17
2	A	2⅝	2¾	2⅞	3 1/16	3 3/16	3½	3 13/16	4¼
	B	1.02	1.04	1.03	1.05	1.05	1.13	1.13	1.19
2½	A	2 15/16	3 1/16	3 3/16	3⅜	3½	3 13/16	4⅛	4½
	B	1.08	1.10	1.10	1.11	1.12	1.19	1.26	1.26
3	A	3¼	3⅜	3½	3¾	4	4¼	4½	4 15/16
	B	1.08	1.10	1.10	1.17	1.17	1.19	1.24	1.24
3½	A	3⅝	3¾	3⅞	4 1/16	4 3/16	4½	4 13/16	5¼
	B	1.14	1.17	1.16	1.24	1.24	1.32	1.39	1.44

Nominal size of conduit, in.	D, in.	E, in.
	oct. hex.	cot. hex.
½	1 1/16–1 7/32	5/32 1/8
¾	1 7/16	5/32
1	1 23/32	3/16
1¼	2 5/16	3/16
1½	2 9/16	3/16
2	3 1/8	7/32
2½	3¾	¼
3	4 1 1/16–4	1 1/32–1 7/32

66. Conduit Nipples

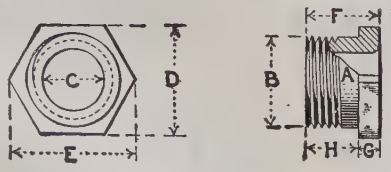


FIG. 37.—Conduit nipple.

Size of conduit, in.	A, threads per in.	B, diam. of threads, in.	C, in.	D, in.	E, in.	F, in.	G, in.	H, in.
½	14.0	0.82	0.62	1.00	1.15	0.62	0.12	0.50
¾	14.0	1.02	0.82	1.25	1.44	0.81	0.19	0.62
1	11.5	1.28	1.04	1.37	1.59	0.94	0.25	0.69
1¼	11.5	1.63	1.38	1.75	2.02	1.06	0.25	0.81
1½	11.5	1.87	1.61	2.00	2.31	1.12	0.31	0.81
2	11.5	2.34	2.06	2.50	2.89	1.31	0.31	1.00
2½	8.0	2.82	2.46	3.00	3.46	1.44	0.37	1.06
3	8.0	3.44	3.06	3.75	4.33	1.50	0.37	1.12
3½	8.0	3.94	3.54	4.25	4.91	1.62	0.44	1.19

67. Rigid-conduit Elbows

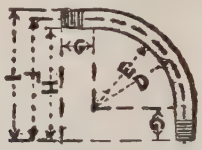


FIG. 38.—Conduit elbow.

Nominal inside diam., in.	Actual inside diam., in.	Actual outside diam., in.	*D*, radius of ℄, in.	*E*, radius, in.	*F*, offset to ℄, in.	*G*, length, straight portion, in.	*H*, offset to inside, in.	*I*, offset to outside, in.	Weight of 100, lb.
½	⅝	27/32	3¾	3 11/32	6 1/16	2 15/16	6 17/64	7/64	83
¾	53/64	1 3/64	4½	4	6 27/32	2 11/32	6 21/64	7⅜	111
1	1 3/64	1 5/16	5¾	5 5/32	8½	2¾	7 27/32	9 5/32	207
1¼	1⅜	1 21/32	6⅝	5 25/32	9 25/32	3 5/32	8 61/64	10 39/64	317
1½	1 39/64	1 29/32	8⅜	7 1/16	11 11/16	3 5/16	10 47/64	12 41/64	441
2	2 1/16	2⅜	9¼	8 1/16	13¾	4½	12 9/16	14 15/16	715
2½	2 15/32	2⅞	10½	9 1/16	15¾	5¼	14 5/16	17 3/16	1,390
3	3 1/16	3½	11¾	10	17¼	5½	15 9/16	19	1,850
3½	3 9/16	4	13¾	11¾	20 7/16	6 11/16	18 7/16	22 7/16	2,650
4	4 1/64	4½	16	13¾	22 7/16	6 7/16	20 3/16	24 11/16	3,470

68. Malleable-iron Conduit Bushings

FIG. 39.—Conduit bushing.

Nominal size of conduit, in.	*A*, in.	*B*, in.	*C*, in.	*D*, in.	*E*, in.
⅜	25/32	27/32	15/32	3/16	11/32
½	15/16	1 1/32	19/32	¼	13/32
¾	1 5/32	1¼	¾	¼	15/32
1	1 13/32	1 17/32	31/32	5/16	17/32
1¼	1 11/16	1 29/32	1 5/16	⅜	19/32
1½	2 1/16	2 5/32	1 17/32	13/32	⅝
2	2 9/16	2 11/16	1 15/16	13/32	21/32
2½	3 1/16	3 5/32	2 1/32	15/32	¾
3	3 11/16	3 25/32	2 27/32	17/32	⅞

69. Table 66 of conduit-nipple dimensions is, since the function of the nipple is about the same as that of the bushing, used for the same purposes as the bushing table. The nipple screws into a coupling (see Fig. 35), while the bushing screws onto the threaded end of a length of conduit. The nipple is more compact than the bushing and hence is perferable for some work.

70. Punched-steel lock nuts are shown in Table 65. Lock nuts are used on conduit on the outside of the box wherever the conduit enters an outlet box, and their dimensions must often be known in laying out panel or outlet boxes, so that proper turning clearances can be provided for the nuts.

71. Table 65 of conduit spacings for different clearances between conduits and their lock nuts or nipples is exceedingly valuable to a man who is designing or erecting conduit work. From it he can determine directly just what the distance between centers of conduits should be for given clearances between nipples or conduit. These data are indispensable when laying out the centers of a row of holes through which conduit is to enter a panel box, or in laying out the supports for a multiple-conduit run.

72. The National Electrical Code specifies the size of conduit to use, depending upon the number, type, and size of conductors to be installed therein. The proper size of conduit can be determined from the following tables in Div. 11:

1. For ordinary 600-volt wiring..... Table 21
2. For 600-volt, lead-covered cables..... Table 22
3. For more than nine conductors in specially approved locations..... Table 23
4. For rewiring, using existing conduits..... Table 24
5. For combinations of different sizes of conductors in the same conduit the sum of the cross-sectional areas of the conductors must not exceed the percentage internal area of the conduit given in Table 24. The cross-sectional areas of 600-volt conductors are given in Tables 26, 27, and 27*A*. If a type of conductor not included in Tables 26, 27, or 27*A* is to be used, the area may be determined from the diameter of the cable as given in Div. 2. For the internal area of the conduit see Table 25.

Example.—Determine the size of conduit required for three No. 8 wires and three No. 2 wires. All wires are of Type R.

Solution.—From Table 26 of Div. 11 the area of a No. 8 wire is 0.071 sq. in., that of a No. 2 wire is 0.21 sq. in. The total wire area = $(3 \times 0.071) + (3 \times 0.21) = 0.213 + 0.63 = 0.843$ sq. in. From Table 24 of Div. 11 for conductors not lead covered, over four in a conduit, 40 per cent of the internal conduit area may be occupied. The internal area of the conduit must be, therefore, at least as great as 0.843/0.4, or 2.11 sq. in. From Table 25 of Div. 11, a 2-in. conduit will be required. Although this conduit has an area considerably larger than required, the next smaller size (1½ in.) is too small.

73. Outlets for lighting luminaires and wiring devices require the use of outlet boxes or conduit fittings. Outlet boxes are usual for concealed conduit work, and conduit fittings are usual for exposed conduit.

74. Outlet boxes that are used for conduit wiring are of sheet steel, preferably coated with zinc. They not only hold the conduit ends firmly

in position and form a pocket for enclosing wire joints but also constitute electrical connectors between the elements of the conduit system, all of which must be in good electrical contact. Each conduit run in an installation must terminate in an accessible outlet box. Outlet boxes are made in many different forms. For complete data and descriptions of outlet boxes see Div. 4. The required size of boxes is given in Sec. **238.**

75. All boxes should be installed so that the outer edge of the box or the cover mounted on the box will come flush with the surface of the plaster. The top of an outlet or junction box must never be concealed, as the wire splices inside must be accessible for inspection. The conduit must be fastened securely to the box by using a lock nut on the outside and a bushing on the inside of the box.

76. Conduit junction boxes, which are in reality nothing more than pull boxes on a large scale, are often very convenient at points where

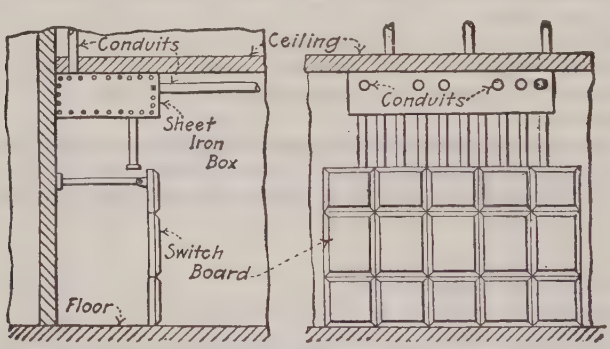


FIG. 40.—A sheet-iron conduit junction box.

several conduit lines intersect, as for instance over a switchboard (Fig. 40) from which conduit lines radiate. The junction box is usually supported from the ceiling and is best made of sheet iron on an angle-iron frame. The sides should be held on with machine screws turning into tapped holes in the frame so that they can be readily removed. Round holes can be cut in the sheet-iron sides for the conduits, or, often preferably, slots can be provided instead. The conductors within the box can be carried from conduit outlet to conduit outlet in any direction desired, and the use of elbows and troublesome conduit crossings can thereby be avoided.

77. Pull boxes can often be advantageously substituted for elbows (Fig. 41). Large elbows are expensive. Where there are three or more right-angle turns in a run, a pull box should be inserted in any event. One pull box may be substituted for several elbows. Wire can be pulled in more readily where there are pull boxes. Pull boxes are generally made of sheet steel (Fig. 41, *I*). Boxes should be made and drilled in

the shop where proper tools are available rather than on the job. The required size of pull boxes is given in Sec. **237.**

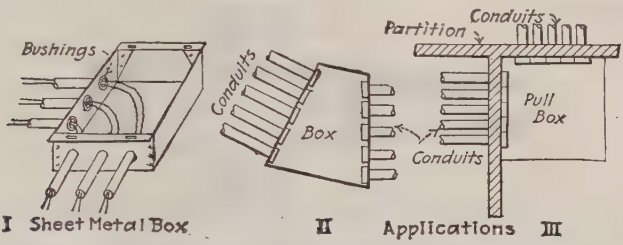


FIG. 41.—Conduit pull boxes.

78. Conduit fittings are appliances used to adapt conduit to different situations and conditions. Figure 42 shows some popular fittings, the applications of which are obvious. The National Electrical Code specifies that every conduit outlet must be equipped with an outlet box or approved fitting. A fitting like that of I or II placed on a conduit end fulfills this requirement. Elbows, crosses, and tees, as in III, V, and VI, respectively, can be obtained fitted with either metal or composition or porcelain wire-hole covers or with outlet or other devices. The fitting of IV is used on the end of an outdoor piece of conduit into which wires enter. Its shape is such that wires must enter upwardly, preventing the entrance of moisture. As it is almost impossible to pull wires through a fitting of this kind after it is in place it is therefore held to a coupling on the end of the conduit with screws turning into a flange. The wires can be pulled into the conduit and the fitting slipped over them and attached to the flange without it being necessary to turn the fitting. The fittings of VII and VIII can be used either as pull boxes, to support switches, or for a number of other purposes. Everyone interested in wiring should have the catalogues of the fitting manufacturers. These illustrate a great number of fitting combinations and applications.

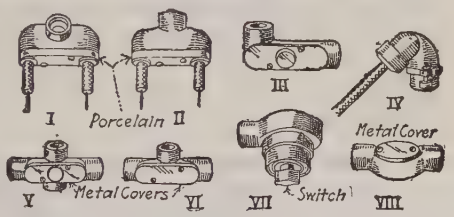


FIG. 42.—Some popular conduit fittings.

Conduit fittings are made with their hubs for attachment to the conduit of either the threaded or threadless types.

79. Threadless fittings (Fig. 43) can be used with unthreaded conduit. Tightening a bushing or a lock nut clamps the conduit within the fitting. Threadless fittings materially reduce the labor cost of conduit installa-

tion. They do not, however, provide as great mechanical strength as threaded fittings.

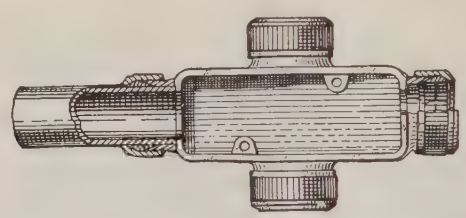


FIG. 43.—No-thread conduit fitting. (*Appleton Electric Co.*)

80. Conduit should run as straight and direct as possible. There should never be more than the equivalent of four right-angle bends between drawing-in outlets.

81. In installing exposed conduit runs where there are several conduits in the run it is usually better to carry the erection of all of them along together rather than to complete one line before starting the others. If all are carried along together it is easier to keep all the ducts parallel, particularly at turns, and the chances are that the job will therefore look better.

82. Galvanized-iron Pipe Straps of the Two-hole Type

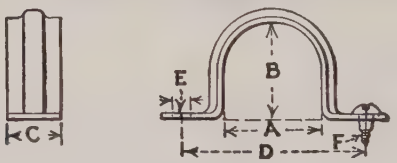


FIG. 44.—Pipe strap.

Nominal size of conduit, in.	*A*, width of opening, in.	*B*, height of opening, in.	*C*, width of strap, in.	*D*, distance between centers of screw holes, in.	*E*, diam. of screw hole, in.	*F*, size of wood screw to use	Approximate number per lb.
						No. in.	
¼	9/16	17/32	5/8	1 9/16	0.20	8 × 5/8	75
3/8	1 1/16	2 1/32	5/8	1 3/8	0.20	8 × 3/4	72
½	7/8	2 5/32	5/8	1 5/8	0.20	8 × 3/4	40
3/4	1 1/8	1	3/4	2 1/8	0.22	10 × 3/4	29
1	1 3/8	1 11/32	3/4	2 3/8	0.22	10 × 7/8	21
1¼	1 3/4	1 5/8	1 3/16	2 3/4	0.22	10 × 1	18
1½	2	1 7/8	1 3/16	3	0.22	10 × 1	14
2	2½	2 5/16	1	3 3/4	0.22	10 × 1¼	12
2½	2 3/4	2 15/16	7/8	4 3/8	0.25	11 × 1¼	6

83. Conduit can be supported on surfaces with pipe straps which are made in two-hole (Fig. 44) and one-hole (Fig. 45) types. On wooden surfaces, wood screws secure the straps in position. On masonry surfaces, machine screws turning into lead expansion anchors can be used. (Refer to Div. 4 for types of expansion anchors.) Wooden plugs should never be used because no matter how well seasoned a plug appears to be it will usually dry out some and loosen in the hole. The dimensions in

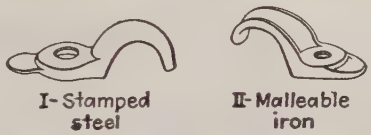


FIG. 45.—One-hole pipe straps. (*General Electric Supply Corp.*)

Table 82 are valuable, when laying out multiple-conduit runs, to determine the spacings necessary between the conduits to allow for proper placing of the straps. The screw-hole dimensions enable one to order, in advance, screws of the proper diameters to support the straps. Unfortunately, there are no standard dimensions in use by all the manufacturers of pipe straps, and those furnished by different makers will vary somewhat in size. The dimensions given are from one manufacturer's line, and are typical. Where conduit is carried on the flanges of I beams one of the many commercial clamps can be used, or the one referred to in Sec. **86** can be applied. Conduit can also be supported on an I beam by first

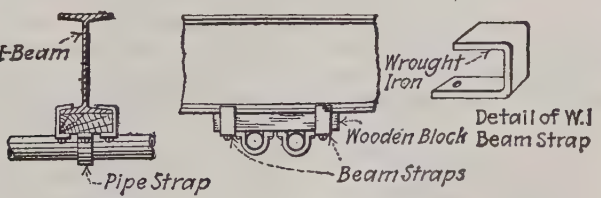


FIG. 46.—Application of beam straps.

clamping a wooden block to the beam and then securing the conduit to the block with pipe straps (see Fig. 46).

84. Location of Conduit Supports.—The National Electrical Code does not specify the spacing for conduit supports, merely stating that the conduit must be securely fastened in place. The Electragist Standards published by the National Electrical Contractors' Association give the following rules, which are intended as a guide for high-grade work and need not be rigidly adhered to in order to comply with the intent of the Code.

85. Spacing of Conduit Supports

Conduit size, in.	Number of conduits in run	Location	Maximum spacing of supports, ft.
		Horizontal Runs	
½, ¾	1 or 2	Flat ceiling or wall	5
½, ¾	1 or 2	Where it is difficult to provide supports except at intervals fixed by the building construction	7
½, ¾	3 or more	Any location	7
1 and larger	1 or 2	Flat ceiling or wall	6
1 and larger	1 or 2	Where it is difficult to provide supports except at intervals fixed by the building construction	10
1 and larger	3 or more	Any location	10
		Vertical Runs	
½, ¾	.....	Exposed	7
1, 1¼	.....	Exposed	8
1½ and larger	.....	Exposed	10
Up to 2	.....	Shaftway	14
2½ and larger	.....	Shaftway	28
Any	.....	Concealed	10

86. Some commercial I-beam conduit hangers are shown in Fig. 47. The one at I is an I-beam clamp formed from wrought-iron strap. The hanger or clamp—the part that grips the beam—of that at II can be purchased of either stamped steel or malleable iron. The support—

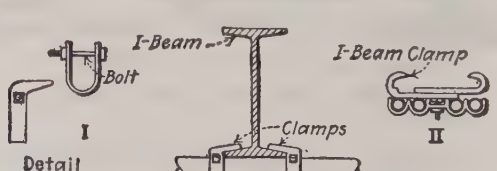


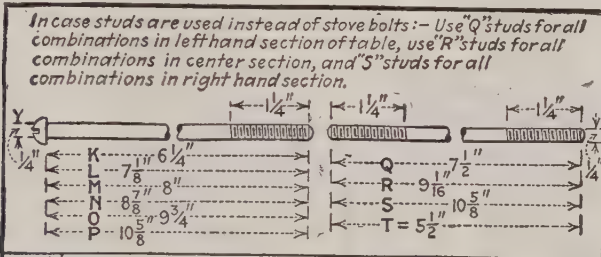
FIG. 47.—Commercial conduit clamps.

the yoke in which the conduits rest—is of malleable iron and can be purchased to accommodate one or several conduits of different sizes.

87. The I-beam conduit clamps of Table 89 will be found of great convenience in steel-mill- and fireproof-building work. Their principal advantage is that they draw the conduit up closely against the I beam

and grip it very firmly. In a multiple-conduit run each conduit can be secured to a given beam with its own pair of clamps. Where the clamps are used on conduits in a group that lie close together the stove bolts should be used in preference to the studs so that they can be drawn up with a screw driver. For a single isolated conduit, either studs or stove bolts can be used.

88. Fig. 48 shows the size of the stove bolts or of the studs that should be used with a given I beam and a conduit of a given size. Stove bolts



CONDUIT	SIZE OF I BEAMS								
	4"	6"	7"	8"	9"	10"	12"	15"	18"
½"	T 5½"	K 6¼"	K 6¼"	K 6¼"	K 6¼"	L 7⅛"	M 8"	N 8⅞"	O 9¾"
¾"		K 6¼"	K 6¼"	K 6¼"	K 6¼"	L 7⅛"	M 8"	N 8⅞"	O 9¾"
1"		K 6¼"	K 6¼"	K 6¼"	K 6¼"	L 7⅛"	M 8"	N 8⅞"	O 9¾"
1¼"		K 6¼"	K 6¼"	K 6¼"	K 6¼"	L 7⅛"	M 8"	N 8⅞"	O 9¾"
1½"		K 6¼"	K 6¼"	K 6¼"	K 6¼"	L 7⅛"	M 8"	N 8⅞"	O 9¾"
2"		K 6¼"	K 6¼"	K 6¼"	K 6¼"	L 7⅛"	M 8"	N 8⅞"	O 9¾"
2½"		K 6¼"	K 6¼"	K 6¼"	L 7⅛"	L 7⅛"	M 8"	N 8⅞"	P 10⅝"
3"		K 6¼"	K 6¼"	K 6¼"	L 7⅛"	L 7⅛"	M 8"	N 8⅞"	P 10⅝"
3½"		K 6¼"	L 7⅛"	K 6¼"	L 7⅛"	L 7⅛"	M 8"	O 9¾"	P 10⅝"
4		K 6¼"	L 7⅛"	K 6¼"	L 7⅛"	L 7⅛"	M 8"	O 9¾"	P 10⅝"
		Q				R		S	

FIG. 48.—Dimensions of stove bolts and studs for the conduit clamps of Fig. 49.

of the sizes indicated are regularly manufactured but are not always readily obtained. The studs can be easily made by threading the ends of ¼-in., wrought-iron rod. In cramped locations the nuts on the studs can be tightened with pliers.

89. Dimensions of I-beam Conduit Clamps.—Clamps are to be made of cast or malleable iron (see Fig. 48 showing dimensions of stove bolts and studs for clamps).

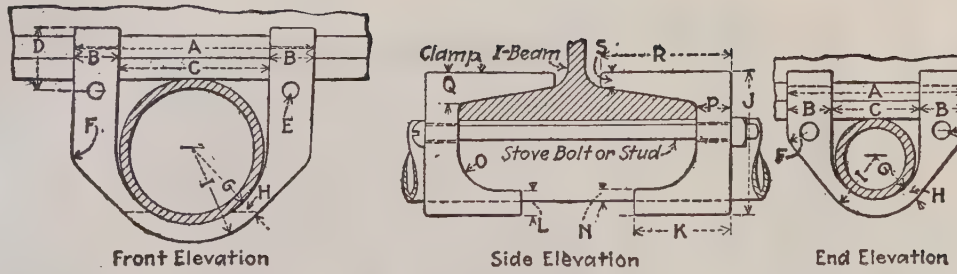


FIG. 49.—I-beam conduit clamp.

Size, I beam, in.	Size of conduit, in.	A	B	C	D	E	F	G	H	I	J	K	L	N	O	P	Q	R	S
4	½	2 5/16	1 1/16	1 5/16	3/4	5/16	1 1/32	1 5/32	1/4	2 3/32	1 11/16	1½	3/8		½	½	1 1/32	1½	1/16
6–18	½	2 5/16	1 1/16	1 5/16	1 1/8	5/16	1 1/32	1 5/32	1/4	1 13/16	2	1½	3/8	1/8	½	¼	1 5/32	2 1/8	3/16
	¾	2½	1 1/16	1 1/8	1 1/8	5/16	1 1/32	9/16	¼	2 3/32	2 ¼	1½	3/8	1/8	½	9/16	1 5/32	2 1/8	3/16
	1	3	¾	1 ½	1 7/32	5/16	3/8	¾	¼	1	2 5/8	1 5/8	7/16	3/16	1 1/16	9/16	33/64	2 3/16	¼
	1¼	3¼	¾	1 ¾	1 3/16	5/16	3/8	7/8	¼	1 1/8	2 2 3/32	1 5/8	7/16	3/16	1 1/16	9/16	33/64	2 3/16	¼
	1½	3½	¾	2	1 3/16	5/16	3/8	1	5/16	1 5/16	3 3/16	1 7/8	½	3/16	1 1/16	9/16	33/64	2 3/16	¼
	2	4	¾	2 ½	1 ¼	5/16	3/8	1 ¼	5/16	1 9/16	3 ¾	1 7/8	½	3/16	1 1/8	5/8	37/64	2 ¼	5/16
	2½	4¾	7/8	3	1 15/32	5/16	7/16	1 ½	5/16	1 13/16	4 ½	2	9/16	¼	1 ¼	1 1/16	41/64	2 5/16	3/8
	3	5¾	1	3 ¾	1 5/16	5/16	1	1 7/8	3/8	2 ¼	5 1/8	2 1/8	9/16	3/16	1 ¼	1 1/16	41/64	2 3/8	3/8
	3½	6¾	1 ¼	4 ¼	1 3/8	5/16	1 ¼	2 1/8	½	2 5/8	5 11/16	2¼	11/16	3/16	1 ¼	13/16	1 1/16	2 15/32	7/16
	4	7½	1 3/8	4 ¾	1 7/16	5/16	1 3/8	2 3/8	½	2 7/8	6 ¼	2¼	¾	¼	1 ¼	13/16	2 9/32	2 7/16	½

90. A hanger for supporting conduit on hollow tile (Fig. 50) is made by the Yonkers Specialty Co., Yonkers, N.Y. With it only one hole is necessary through the tile, which is considerably weakened by the two holes and plugs close together that are necessary for a pipe strap. The flexible metal strap is bent around the pipe and through the slot after the conduit is in position.

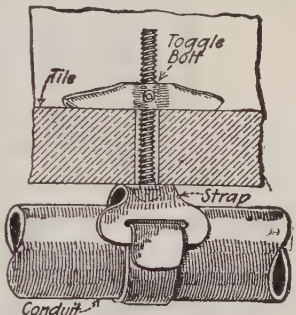


FIG. 50.—Conduit toggle bolt.

91. Conduit in fireproof buildings is usually carried over and is supported by the floor beams (Fig. 51) when carried within the floors. Where necessary the terra-cotta fireproofing is channeled to receive it. In vertical runs in walls or partitions the fireproofing is either channeled for or built around the conduit, which is held in place with cut nails or pipe hooks prior to plastering.

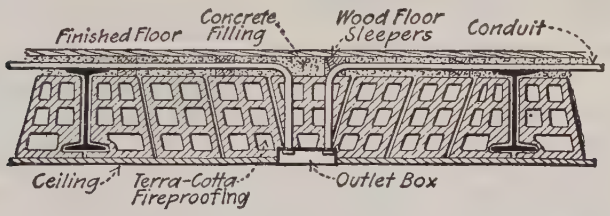


FIG. 51.—A fixture outlet in a terra-cotta ceiling.

92. Conduit in concrete buildings—much of it at any rate—should be installed while the building is being erected. The outlets and the conduit between outlets should be attached to the forms, and the concrete can be poured around them (Fig. 52). Where several conduits are to

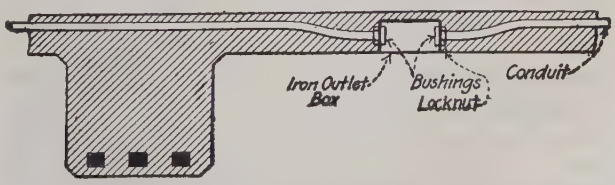


FIG. 52.—Conduit and outlet box in concrete.

pass through a wall, partition, or floor, a plugged sheet-iron tube (Fig. 53, I) should be set in the forms to provide a hole for them in the concrete. Where a single conduit is to pass through, a nipple (Fig. 53, II) can be set in the forms.

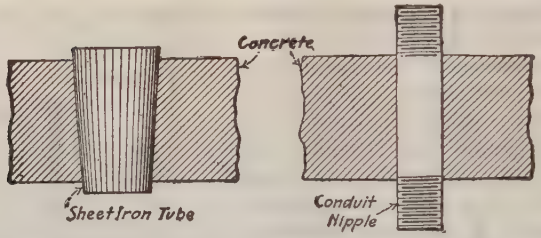


FIG. 53.—Methods of providing passages through concrete.

93. A method of supporting exposed conduit wiring in concrete buildings is shown in Fig. 54. A round groove of ⅜-in. radius is cast in the faces of the beams, by having ¾-in. half-round molding nailed in the forms. Wrought-iron yokes are bent to fit the grooves as shown, and ½-in. bolts clamp them in position.

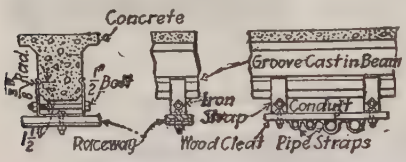


FIG. 54.—Supporting conduits on a concrete beam.

94. Conductors in vertical conduits must be supported within the conduit system as indicated in the following table:

Conductor Size, No. of Cir. Mils	Spacing between Supports, Ft.
No. 18–0	100
No. 2/0–4/0	80
250,000–350,000	60
350,001–500,000	50
500,001–750,000	40
750,001 and larger	35

The following methods of supporting cables are recommended by the Underwriters:

1. Approved clamping devices constructed of or employing insulated wedges inserted in the ends of the conduits (Fig. 55). With cables having varnished-cambric or thermoplastic insulation it may also be necessary to clamp the conductor.

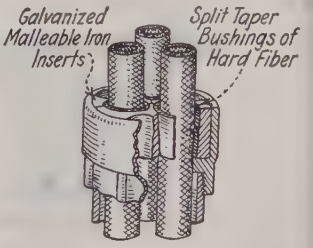


FIG. 55.—Cable support screwed on end of conduit.

2. Junction boxes may be inserted in the conduit system at the required intervals, in which insulating supports of approved type must be installed and secured in a satisfactory manner so as to withstand the weight of the conductors attached thereto, the boxes to be provided with proper covers.

3. Cables may be supported (Fig. 56) in approved junction boxes on two or more insulating supports so placed that the conductors will be deflected at an angle of not less than 90 deg., and carried a distance of not less than twice the diameter of the cable from its vertical position. Cables so suspended may be additionally secured to these insulators by tie wires.

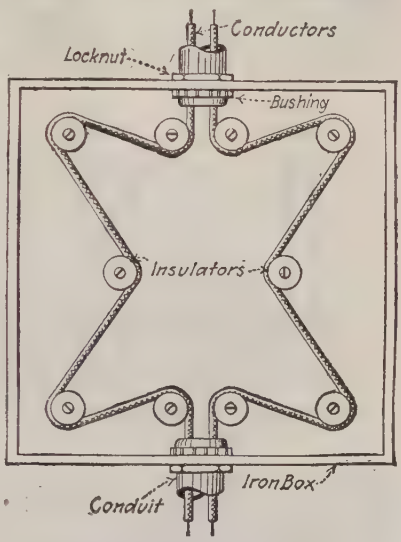


FIG. 56.—Supporting conductors in a vertical conductor run.

95. Properly bent conduit turns look better than elbows and are therefore preferable for exposed work (see Fig. 57). If bends are formed to a chalk line, drawn as suggested in Sec. **96**, the conduits can be made to lie parallel at a turn in a multiple run as shown at Fig. 57, II. If standard elbows are used it is impossible to make them lie parallel at the turns. They will have an appearance similar to that shown at I.

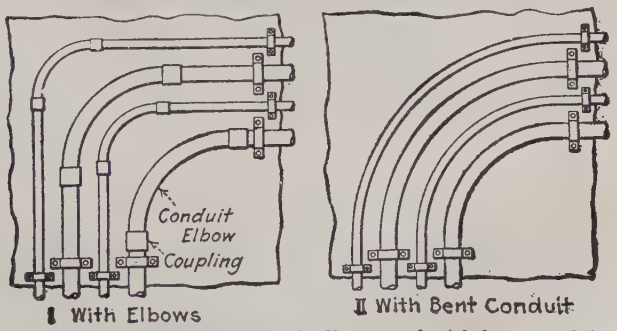


FIG. 57.—Right-angle turns with elbows and with bent conduit.

96. To Lay Out a Right-angle Conduit Bend.—Draw a chalk-line diagram of the contour of the bend on the floor as follows (see Fig. 58): Draw a base line *CO* of any length. Lay off *AO* 4 units long. (The units may be any dimensions whatever.) With a cord and a piece of chalk with *O* as a center and a radius of 3 units describe the arc *IJ*. With *A* as a center and a radius of 5 units describe the arc *EH*. The line *OD* drawn

from O through B, the intersection of the two arcs, will be at right angles with CO.

CO and OD may now be prolonged for any desired distance. The arc CD is drawn with the cord and chalk with any required radius R. The conduit bend should lie parallel to this arc when the bend is laid on the

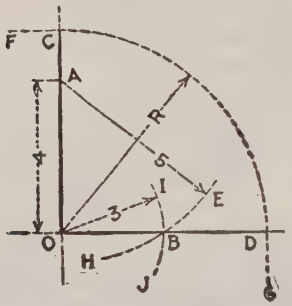


FIG. 58.—Laying out a right angle.

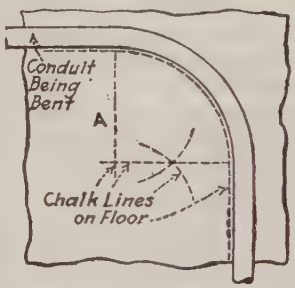


FIG. 59.—Forming a conduit to chalk lines.

floor for inspection as shown in Fig. 59. The radius of curvature of the inner edge of any field bend is required by the code to be not less than shown in the following table:

Minimum Radius of Conduit Bend, Inches

Size of conduit	Conductors not lead covered	Lead-covered conductors
½	3.7	6.2
¾	4.9	8.3
1	6.3	10.5
1¼	8.3	13.8
1½	9.6	16.1
2	12.4	20.6
2½	14.8	24.6
3	18.4	30.6
3½	21.3	35.5
4	24.1	40.2
4½	27.0	45.0
5	30.3	50.4
6	36.4	60.6

97. Hand conduit benders are shown in Fig. 60. Many satisfactory commercial benders are obtainable, but they usually have the disadvantage that the work must be carried to them to be bent. The

"hickeys" shown at I can be used anywhere and hence are very popular. For $\frac{1}{2}$- or $\frac{3}{4}$-in. conduit the "hickey" should be a 1-in. tee and pipe. A bender with a grooved metal wheel that any one can make is shown at II. The arrangement of III can be used for large conduit. It consists of two heavy wooden blocks bolted to a column or other substantial vertical support.

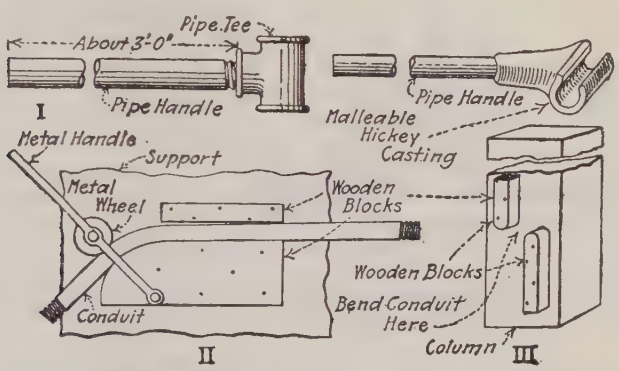


Fig. 60.—Some conduit-bending appliances.

98. To bend conduit by hand, butt the end in which the bend is not to be made against a wall or other vertical substantial object and mark off on the floor, with a line, the point where the bend should come. Slip the bender onto the pipe to a point within a couple of inches of the mark. Then bend the conduit about 20 deg. (Fig. 61, I). Move the bender back an inch or so and bend some more. Repeat until the bend assumes the proper form. Make all bends with as large a radius as possible.

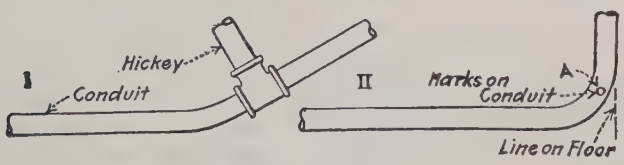


Fig. 61.—Bending conduit by hand.

Where a line is drawn on the floor, conduit can be bent accurately to it (Fig. 61, II), but if a mark is placed on the conduit as at *A* it is very difficult to make a proper bend.

99. A combination conduit vise and bender for conduit of the smaller sizes is shown in Fig. 62. By bolting the casting shown at II to a commercial vise the arrangement shown at I results. The best vise for large

conduit is the so-called combination vise, which is a combination of a pipe vise and a machinist's vise.

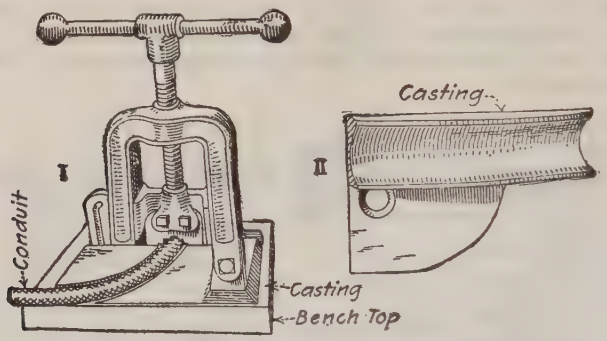


FIG. 62.—Combination vise and bender.

100. Cold Bending Large Conduit.—A rig for doing this is shown in Fig. 63. The bending rig can be set up in a doorway or between any

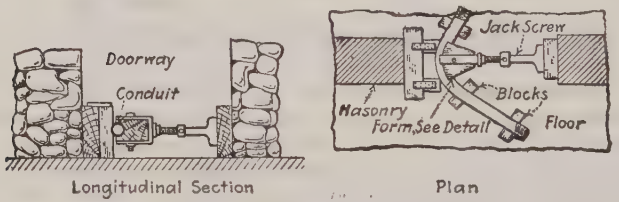


FIG. 63.—Cold bending conduit with a jackscrew.

strong vertical supports. It is usually cheaper to bend large elbows than to buy them. Always carefully lay out a chalk line (see Sec. **96**) on the floor to bend to before starting. In forming a bend, start at one end of the curve that is to be, bend a little with the jackscrew, and then take the conduit out and to the chalk line and compare it therewith. Proceed thus until the bend required is formed. A hydraulic jack rather than a jackscrew may be necessary for conduits larger than 2 in. in diameter.

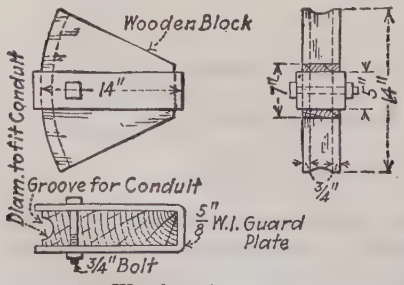


FIG. 64.—Wooden form for bending conduit.

101. The wooden form by means of which the jackscrew's pressure is applied to the conduit is de-

tailed in Fig. 64. It should be of a hard close-grained wood such as maple. The diameter of the groove should be a trifle larger than that of the conduit. There should be a block for each size conduit, but sometimes a conduit can be successfully bent with a block for a larger size. If the groove does not fit, the pipe may crush. The iron strap reinforces the groove. The bolt should fit tightly the hole for it in the block, or the block may crush. The radius R (Fig. 58) should be not less than that of standard elbows (see Table 65).

102. Threading Conduit.—The same dies that are used by steam and gas fitters for threading pipe are used for threading conduit. It is usual practice when a lot of conduit is received to rethread all the ends which may have become filled with paint or dirt or distorted by blows. Rethreading will save more than its cost in that it ensures rapid erection. Always ream conduit after cutting a thread on it. Pipe-threading machines for threading conduit, preferably those operated by motors, should be used on big jobs as they will soon pay for themselves in the time that they save.

103. Wrenches for Turning Conduit.—The form of wrench shown in Fig. 65, I appears to be the most popular for turning conduit. Chain

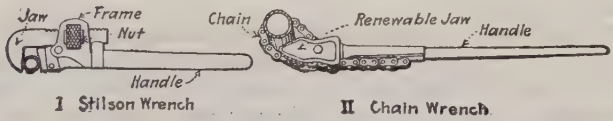


Fig. 65.—Wrenches for conduit.

wrenches (II) are not as yet much used for conduit work, but in instances where they have been tried they have proved very satisfactory. Their advantages lie in the facts that they can be used with one hand after the chain is around the conduit and that they can be used in confined places and close to walls where a Stilson wrench could not be utilized.

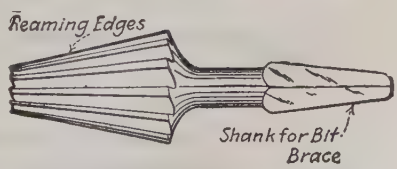


Fig. 66.—A bit-brace reamer.

104. Conduit ends should always be reamed. A reamer like that of Fig. 66 which can be turned by a bit brace is a good tool for small and medium-sized conduit. For conduit of the larger sizes, reamers which have long handles attached, giving the needed leverage, can be obtained. When conduit is received, and after it is cut, the ends are frequently turned in (Fig. 67, I) and, when screwed together in a coupling, form a knifelike edge which will abrade insulation. When the ends are properly reamed they appear as shown in Fig. 67, II, but if they are screwed

together too tightly they may turn up as at I, defeating the thing that reaming should accomplish. Where no other tool is available, conduit can be reamed by hand with a half-round file.

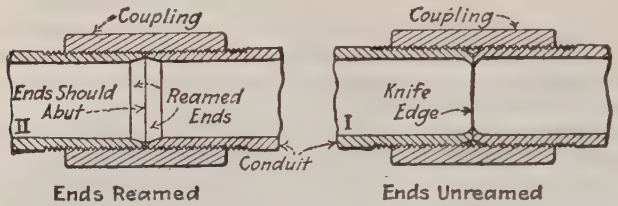


FIG. 67.—Reamed and unreamed conduit ends.

105. The best tool for cutting conduit is a hack saw. Pipe cutters are frequently used but leave a large burr on the inside of the conduit, which takes time to ream out. While cutting, the conduit should be held in a vise. On jobs where there is a great deal of conduit to cut, the installation of a motor-driven, cold-cutoff saw, such as is used for cutting structural steel and rails, will prove economical. A rapidly rotating steel disk without teeth cuts the pipe. Water must be sprayed on the disk to keep it cool.

106. Fishing wire is tempered steel wire of rectangular cross section. It is a grade of wire that is used sometimes for corset steels and can be obtained at corset factories and at electrical supply houses. A fishing wire is termed a "snake" by some wiremen (see Table 109). So that

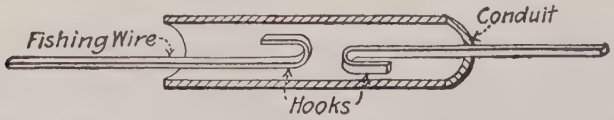


FIG. 68.—Hooks bent in fishing-wire ends.

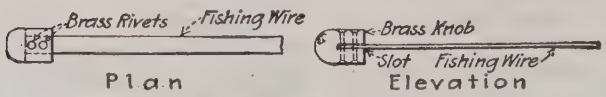


FIG. 69.—Knob on end of fishing wire.

a fishing wire will slide readily past small obstructions, hooks should be bent in its ends as shown in Fig. 68. Before bending, the ends should be annealed by heating them to a red heat and allowing them to cool slowly. A small brass knob riveted to the end of a fishing wire (Fig. 69), is better than a hook as regards the ease with which the wire can be pushed through conduit. Where fishing is difficult, it is sometimes necessary to push two "snakes" with hook ends into the wireway, one from each of the outlets, as shown in Fig. 68. The wires must be worked back

and forth and twisted around until the two hooked ends engage. Then one wire can be pulled into the duct with the other. The Swan fishing wire for conduit, shown in Fig. 70, has a patented coupling on one end and a patented drawing-in eye on the other, which can be made to engage within conduit, as shown in the illustration.

107. When fishing from two ends, as in Fig. 68, it is often advisable to tie a loop of cord, possibly 1 ft. long, in the hook of one wire and bend

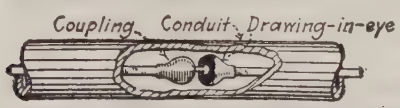


FIG. 70.—"Swan" coupling and drawing-in eye.

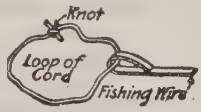


FIG. 71.—Cord loop on end of fishing wire.

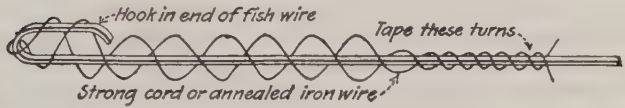


FIG. 72.—Fish-wire end prepared with cord.

down the hook (Fig. 71). The other wire has an open hook which can be made to engage in the cord loop quite readily. It has been found that a fish wire will go through conduit more readily if prepared as in Fig. 72, by loosely winding the end with small wire or cord, so that the wire or cord cannot pull off. Oiling a fish wire or attaching an oil-soaked piece of waste to its end often helps in fishing conduit.

108. Chain is used for vertical fishing. A small chain can be made to drop down a vertical wireway with little difficulty. Within a partition, the noise made by the lower end of a chain that is jiggled up and down will disclose its location almost exactly.

109. Galvanized-steel wire can be used for fishing. Any size from No. 14 up to, possibly, No. 6, as occasion demands, may be utilized, but in nearly every case the flat steel ribbon wire will be found preferable.

110. Dimensions of Steel Fish Wire

The ¼-in. width of wire is the size most frequently used. The wire is usually put up in coils of 50, 75, 100, 150, and 200 ft.

W, width, in.	*T*, thickness, in.	Weight per 100 ft.
⅛	0.015	11 oz.
⅛	0.030	1 lb. 4 oz.
5/16	0.030	1 lb. 14 oz.
¼	0.030	2 lb. 8 oz.
5/16	0.035	3 lb. 8 oz.
⅜	0.035	3 lb. 12 oz.

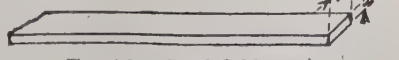


FIG. 73.—Steel fishing wire.

111. In drawing wire into conduit it is a mistake to use so much force that the wire cannot be withdrawn. Conduits should be big enough so that excessive force is not necessary. Duplex No. 14 conductors can often be pushed through "easy" runs. Small conductors (Nos. 14 and 12) can be pulled in with the fish wire. Figure 74 shows how they can

FIG. 74.—Attachment of conductor to fishing line.

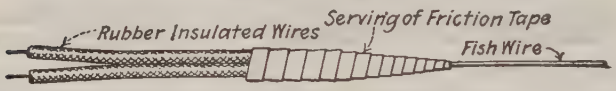


FIG. 75.—Attachment taped over.

be attached to the fish wire, and Fig. 75 shows how the attachment should be served with tape to render pulling easy. It spoils any fishing wire to draw in with it conductors that pull hard.

For conductors larger than No. 12 and No. 14, unless the "pulls" are very easy, a pulling-in line which is drawn into the conduit with the fish wire should be used for hauling in the conductors. Number 10 or 12 Birmingham wire gage galvanized-steel wire makes a good pulling-in

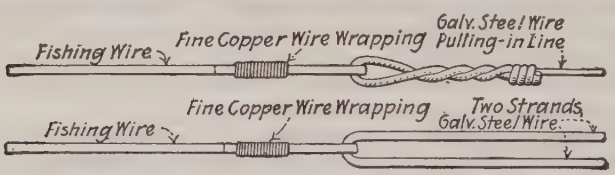


FIG. 76.—Attachment of pulling-in line to fish wire.

line and is probably better for heavy work than rope. Two strands can be used if necessary. Braided cord is better than twisted rope for a pulling-in line, because when, tension is applied, the rope tends to untwist. Sash cord is satisfactory for light work. Galvanized-steel, pulling-in wire can be attached to fish wire as in Fig. 76.

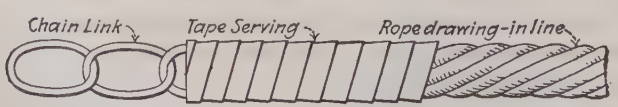


FIG. 77.—Chain links in end of pulling-in line.

Three or four links from a chain of no greater diameter than the line should be made up in the end of a rope or cord pulling-in line. Wires to be drawn in or a fish line can be attached to the links (Fig. 77). One stranded conductor can be attached to a pulling-in line as in Fig. 78.

The attachment should be taped over to make it smooth. If two conductors are to be pulled in, one of them is "made up" into a loop in the end of the pulling-in line, as shown in Fig. 78. The insulation is trimmed from this conductor for 6 in. or more, and the bared end of the other conductor is made up about the first one, forming a long tapering connection. If a hard pull is expected, it is advisable to solder the connection. The whole should be served with tape as in Fig. 75. If three wires are to be drawn in instead of two, the attachment is the same with the addition that the bared end of the third conductor is made up around the other two. The diameter at any section of the attachment must not exceed the over-all diameter of the wires, and the attachment should

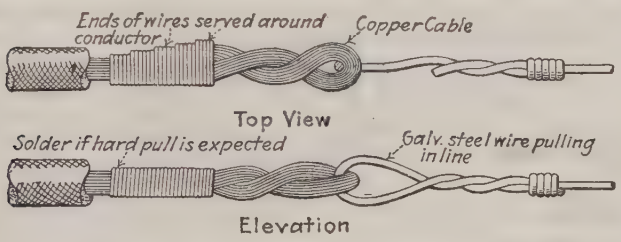


FIG. 78.—Attachment of stranded conductor to pulling-in line.

be in the form of a conical wedge. It is sometimes necessary to cut off possibly half of the strands of the bared ends and make up only the strands that remain to ensure that the attachment will be of sufficiently small diameter.

112. Force for pulling-in conduit is, in the case of easy pulls, supplied by men. Tackle blocks are permissible for heavy pulls. Cranes can often be used very effectively where they are available. Snatch blocks can be used to guide the pulling-in line to some point where it can be either pulled with the crane hook or by the crane in traveling along its runway. A lever can be used for hard pulls by either repeatedly fastening the pulling-in line to the lever or by gripping it with a pair of pliers and then prying against the pliers with the lever. Only a short pull is possible with each setting, and a succession of settings and pries is necessary to draw the conductor in.

113. In feeding conductors into conduit, care must be taken that they go in symmetrically and without lapping or twisting. If one conductor crosses another it may make a hump that will wedge in the conduit. Soapstone blown into conduit renders pulling easier. One convenient way to get the powdered soapstone into the ducts is to place it in an elbow, place the elbow to the conduit, and then blow on the elbow. Powdered soapstone should be rubbed on the conductors as they are drawn into conduits, where the pulls are hard.

FLEXIBLE-METAL-CONDUIT WIRING

114. Flexible metal conduit may be used for many kinds of wiring, being in some cases preferable to rigid conduit. Its installation is much easier and quicker than the installation of rigid conduit, the latter coming in short pipe lengths, whereas the former may be had in lengths of 25 to 250 ft., depending on the size of the conduit. Practically the same National Electrical Code rules apply to the flexible as to the rigid conduit. The rules governing the insulation on the wires are the same as for rigid conduit; outlet or switch boxes must be installed at all outlets or switches; the conduit must be continuous from outlet to outlet, must be securely fastened to the boxes, and must be provided with proper bushings.

Flexible metal conduit consists of a single strip of galvanized steel, spirally wound on itself and interlocked in such a manner as to provide a round cross section of high mechanical strength and great flexibility.

Its flexibility together with the continuous length procurable makes its use practicable when rigid conduit would be out of the question. For this reason it may be employed to advantage in finished houses and in frame buildings in place of the other forms of wiring so largely employed in these structures. The conduit is easily fished and requires no elbow fittings. These may be made with the conduit itself; but care should be exercised in properly fastening the conduit at elbows (Fig. 79). Fittings are on the market whereby changes from other forms of wiring may be easily made to flexible-conduit wiring. Iron plates should be used to protect the conduit from nails, where it passes through slots in floor beams or studding. See Sec. **8A** for liquid-tight flexible metal conduit.

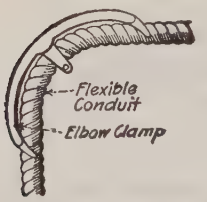


FIG. 79.—Elbow clamp.

115. Standard Sizes of Greenfield Flexible Conduit

FIG. 80.—Greenfield flexible steel conduit.

B, nominal inside diam., in.	*A*, approximate outside diam., in.	Approximate ft. in coil	Approximate weight per 1,000 ft., lb.	*B*, nominal inside diam., in.	*A*, approximate outside diam., in.	Approximate ft. in coil	Approximate weight per 1,000 ft., lb.
5/16	0.470	250	160	1¼	1.665	50	1,480
3/8	0.617	250	180	1½	1.975	25	1,800
½	0.910	100	520	2	2.440	25	2,280
¾	1.090	50	620	2½	3.000	25	2,840
1	1.400	50	1,180	3	3.350	25	3,000

116. Installation of Flexible Steel Conduit.—Where exposed it may be clamped to the surface wired over, either with cable clips or with single-hole straps (Fig. 81). For large sizes the two-hole, rigid-conduit straps may be used. Where concealed, they can be fished into place just as any concealed conductors are fished in.

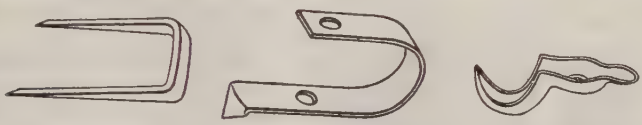


FIG. 81.—Clip and straps for supporting flexible metal conduit. (*General Electric Co.*)

For methods of supporting see Secs. **84** to **90** on supporting of rigid metal conduit.

117. The number and size of conductors to install in flexible metal conduit is the same as for rigid metal conduit (refer to Sec. **72**).

118. Flexible steel conduit is joined with clamps as illustrated in Fig. 82. Short lengths can be coupled to longer pieces with the clamp of I

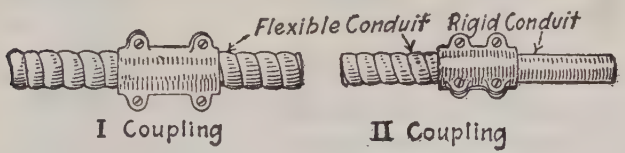


FIG. 82.—Couplings for flexible steel conduit.

and waste thereby prevented. The clamp at II is used for coupling rigid to flexible conduit.

119. Where elbows are formed in flexible conduit, some provision must be made to prevent the conduit from straightening out and thereby preventing the withdrawal of the conductors. Pipe straps can be used in some cases, and in others an elbow clamp (Fig. 79) can be applied.

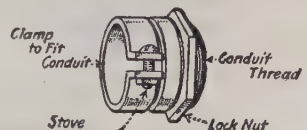


FIG. 83.—Connector for attaching flexible steel conduit to an outlet box.

120. Flexible steel conduit can be connected into steel boxes with the connector illustrated in Fig. 83. It is clamped to the armor with a bolt which insures good electrical connection between armor and steel box. Figure 84 shows flexible steel conduit connected into an outlet box.

121. To cut flexible steel conduit a fine hack saw should be used. Special vises can be purchased which have a slot across their jaws to guide the saw blade, the conduit being held between grooves in the jaws.

122. For reaming flexible steel conduit a special reamer (Fig. 85) has been made, but inasmuch as the burr resulting from the hack saw cut is very small it can be readily removed with a three-corned scraper made from a three-cornered file, or it can be removed with an ordinary file. The reamer illustrated is for conduit of 1¼ in. or less diameter.

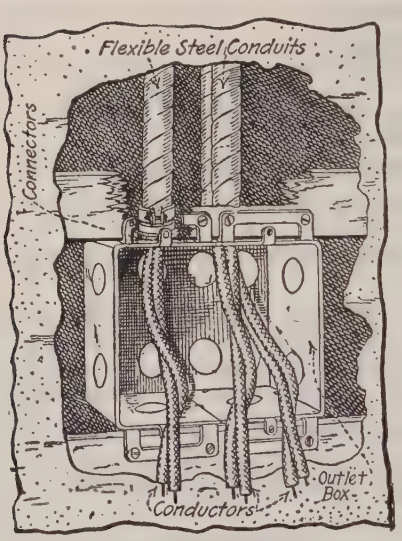


FIG. 84.—Flexible-steel-conduit outlet box.

123. Fish plugs for pulling in flexible conduit (Fig. 86) are furnished by the conduit manufacturer for ⅜-, ½-, and ¾-in. flexible conduit. After the conduit has been cut off square in a vise with a hack saw the fish plug is screwed into the tube and the fish or drawing-in wire attached to the plug for pulling in.

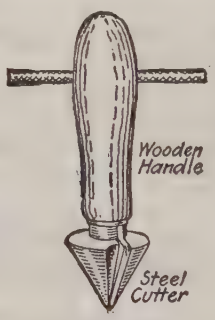


FIG. 85.—Reamer for flexible conduit.

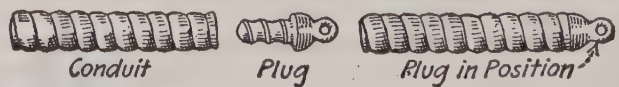


FIG. 86.—Plug for pulling in flexible conduit.

ARMORED-CABLE WIRING

124. Armored cable (Fig. 87) consists of rubber- or thermoplastic-covered wire protected from injury and to a certain extent from dampness by one or two layers of flexible steel armor. The cable may be obtained leaded or unleaded, both being protected with the steel armor. The leaded cable differs from the unleaded in that it has a lead covering between the wire and the steel armor to protect it from excessive dampness. Both the unleaded and leaded cables are made with single and multiple conductors of almost any gage wire for systems of not more

than 600 volts. The leaded armored cable is approved and can be used for all classes of work, including wet locations. The unleaded cable may be used in dry locations.

To install amored cables properly in new buildings, bore holes in the joists and partitions and place the cable in the same manner as wires in concealed knob and tube work; it should always be looped (see Sec. **130**) from outlet to outlet. Where the cable is placed in slots, nails are apt to be driven into it, and, since it is not nailproof, it should be protected at such points with 0.125-in. iron plates. None of the cable should be installed until the roof and floor are in position. In running between

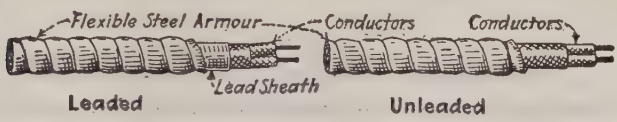


FIG. 87.—Steel-armored conductors.

joists and at outlets the cable should be securely fastened if possible with cable clips or straps so that in case the lock nuts or bushings should fall off at the outlet the fastenings will prevent the cable from pulling out of the box and becoming lost between the joists or studs. The clips and straps are of the same type as illustrated in Fig. 81 for flexible metal conduit.

The wires should extend about ½ ft. beyond the outlet box in order to permit the proper connection of fixtures and switches. In some cities unleaded armored cable is not permitted to be plastered in brick walls or on metal partitions, but where allowed it should be cemented in place and allowed to stand several days before the walls are plastered, so that the cable will be protected from the dampness caused by the wet plaster. The unleaded cable should not be run under tile or cement floors until after these have been laid, because of the dripping water. Armored cable is the next best substitute to rigid conduit, for concealed knob and tube work and also for raceway work.

125. Manipulating Armored Cable.—It must never be spliced except at outlets. Many methods of fastening cable in outlet boxes are in vogue. Special brass terminal bushings or box connectors may be used. Outlet and switch boxes specially adapted for flexible armored cable should be used. Special cutters are available. The armor should be cut square so as not to leave sharp corners which cut into the insulation of the wires.

126. For cutting the cable to length, a shear, bolt cutter, or hack saw may be used. At each outlet or junction box the armor must also be cut back about 8 in. in order to leave sufficient free ends of wire for splicing. This cutting is done with a hack saw held so as to cut across the armor at an angle of about 60 deg. with the axis of the cable (Fig. 88). Great care must be taken not to cut into the insulation on the conductors.

As soon as the hack saw has cut through the armor on one side of the cable the short piece of armor can be unscrewed from the main cable and slipped off the end.

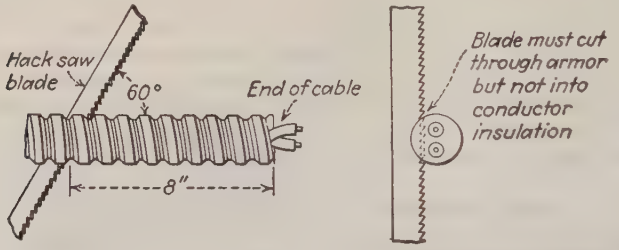


FIG. 88.—Method of cutting armor back from end of cable.

127. The wires at the ends of armored cable should be protected by means of fiber bushings, except that they will not be required with lead-

FIG. 89.—Antishort fiber bushing.

FIG. 90.—Method of protecting wires with antishort bushings.

covered cable. The fiber bushings employed for this purpose are called antishort insulating bushings (Fig. 89). The split bushing is pinched together and slipped over the wires inside the armor, as illustrated in Fig. 90. It protects the insulation of the wires from the rough edges of the cut ends of the armor.

128. For fastening armored cable to outlet boxes a connector (Fig. 91) may be slipped over the end of the cable. The setscrew is tightened down against the armor. The threaded end of the connector slips into

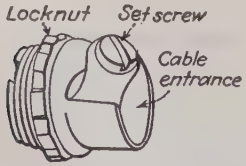


FIG. 91.—Box connector for armored cable. (*General Electric Supply Corp.*)

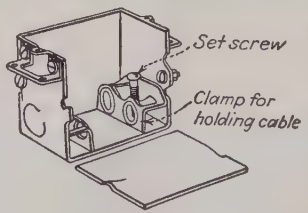


FIG. 92.—Outlet box with clamps for armored cable. (*General Electric Supply Corp.*)

standard conduit knockouts, and the lock nut is then put on, holding the connector tight to the box. Another method is to use outlet boxes of the type shown in Fig. 92, which contain built-in cable clamps in which the clamp tightens down against the armor and holds it firmly in place.

129. Armored Cable for Old Building Wiring.—It can be used to great advantage in this work. An advantage possessed by it is that it can be run with almost utter disregard of its contact with pipes or other materials and can be fished for long distances. Its own weight is sufficient to carry it down partitions, and it is stiff enough to fish between joists without the use of a fish wire. It can also be installed quicker and with less cutting of walls, floors, etc., than can wires in flexible tubing or concealed knob and tube work, and, although a trifle more expensive, it makes a better job. Care should be taken in setting outlet boxes not to depend on laths to hold them, because almost invariably, in hanging and straightening fixtures, they are pulled loose if not securely fastened to a joist, stud, or backboard.

130. The loop system of wiring is nearly always used for concealed work in order to avoid the use of junction boxes. The conductors loop from one outlet to the next outlet, and splices are made only at outlet boxes. All splices must be accessible for inspection, and if a junction box is used the cover must be left accessible.

SURFACE METAL-RACEWAY WIRING

131. Wiring in approved metal raceway can be used for exposed work for circuits having no wire larger than No. 6. Not more than 10 wires may be run in a single raceway. Metal raceway must be continuous from outlet to outlet, junction box, or approved fittings designed especially for use with metal raceway. All outlets must be provided with approved terminal fittings which will protect the insulation of conductors from abrasion, unless such protection is afforded by the construction of the boxes or fittings. Metal raceway should not be used in damp places.

132. Wire for Metal Raceway.—Rubber- or thermoplastic-insulated wire is approved. There is sufficient space in National Metal Molding for four No. 14 or No. 12 or three No. 10 or No. 8 single-braid, rubber-insulated wires. It is often necessary to insert this number at double-pole switch loops, etc. The two or more wires of an a-c circuit must be in the same raceway, and those of a d-c circuit should be, so that, if a change is made to alternating current, reconstruction will not be necessary.

133. National metal raceway, called "La-in," is made by the National Electric Products Corp. of Pittsburgh, Pa. It consists of channel capping that snaps over a channel base. The principal dimensions are given in Fig. 93. It is furnished in lengths of 8 ft. 4 in. It is obtainable either enameled or Sherardized, a process whereby finely divided zinc is driven into the pores of the metal, forming an iron-zinc alloy which is thoroughly rustproof and which cannot be knocked off. Either water or oil paints

adhere well to it. Because of the small space that metal raceway occupies it can be used to advantage on steel ceilings, in show windows, in showcases, and in other locations where appearance is a factor and where safety is essential. In installing National metal raceway, the channel base is fastened to the wall or ceiling with No. 8 wood screws or with

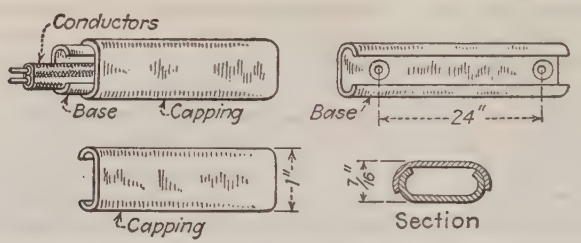


FIG. 93.—Dimensions of National metal raceway.

⅛-, 3/16-, or ¼-in. toggle bolts. The wires are then laid in and held with retaining clips, two of which are supplied with each length of raceway. Finally, the capping is snapped on, enclosing the other material.

One-piece oval raceway intended principally for underplaster extensions is also available (see Sec. **187**).

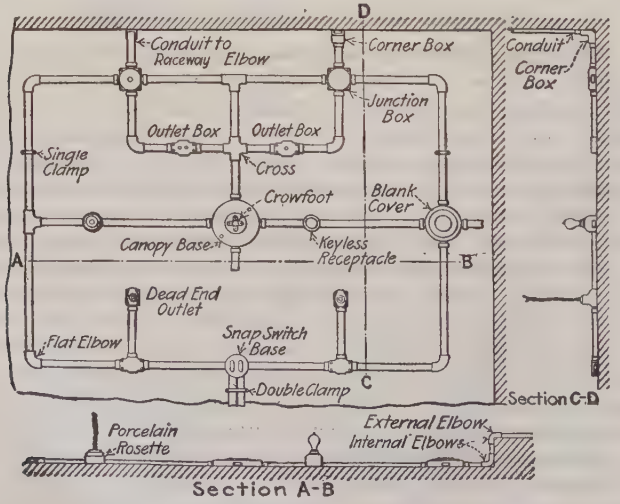


FIG. 94.—Application of metal raceway and fittings.

134. The application of National metal raceway and fittings is illustrated in Fig. 94, an imaginary layout shown to indicate how the material may be used.

135. Xtensionduct (Fig. 95) is a smaller size of La-in metal raceway, made in 5-ft. lengths. This size will take two No. 14 wires and is intended primarily to supply convenience outlets but in some cases is approved for supplying lighting outlets also. Most of the National devices and fittings have knockouts which will accommodate either the Xtensionduct or the standard La-in molding. Xtensionduct is assembled and fastened as described in Sec. **133** except that No. 4 wood screws are used and the retaining clips are not needed.

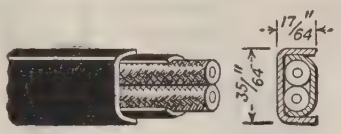


FIG. 95.—Xtensionduct. (*National Electric Products Corp.*)

136. Florduct (Fig. 96) is designed to carry wires from the wall across the floor to desks in office occupancies. It is laid on the surface of the floor and is sufficiently shallow so that if located across aisles which are used only occasionally it does not present any hindrance to the occupants of the office. There are two sizes, the dimensions of which

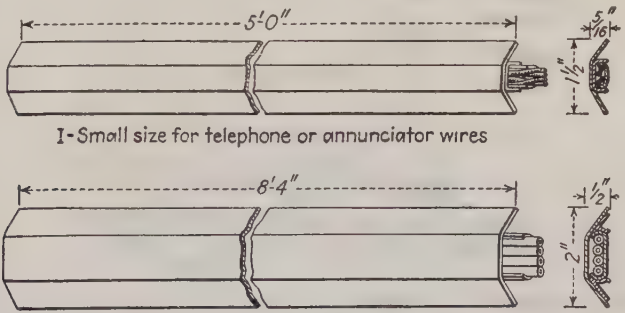


FIG. 96.—Florduct. (*National Electric Products Corp.*)

are shown in Fig. 96. The smaller size (Fig. 96, I) will take four pairs of telephone wire, ten annunciator or bell wires, or two No. 14 power wires. The larger size (Fig. 96, II) will take four No. 14 or No. 12 or three No. 10 or No. 8 power wires or eight pairs of telephone wires or 25 annunciator wires.

137. To install Florduct on wood floors use No. 4 wood screws for the smaller size duct and No. 8 wood screws for the larger size duct. For stone or concrete floors drill a hole about 1 in. deep with a $\frac{3}{16}$-in. drill. A Rawl-drive (Fig. 97) is then driven into the hole with a hammer and firmly grips the sides of the hole in the masonry. After the base of the duct is fastened in this way, the wires are laid in, and the capping is snapped over the base the same as with the other raceways. Figure 98,

representing a completed installation of Florduct, shows the method of attachment to wall-mounted raceway and also shows some of the fittings.

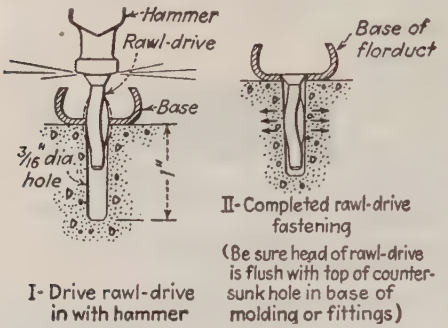


FIG. 97.—Method of fastening Florduct on masonry floor. (*National Electric Products Corp.*)

138. Wiremold metal raceway (Fig. 99, I) consists of a metal capping with its edges crimped over a slightly curved base. The capping is crimped on the base at the factory so that the capping and base are installed as a unit. The wires are pulled through the raceway from fitting to fitting in a manner similar

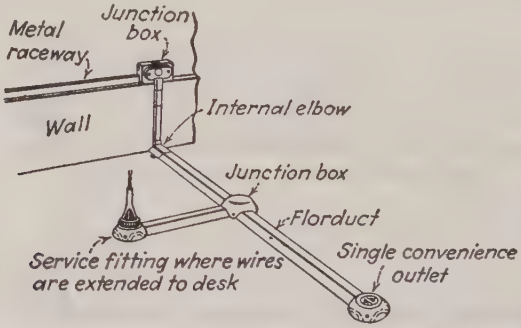


FIG. 98.—Installation of Florduct and outlets. (*National Electric Products Corp.*)

to that employed in conduit work. Wiremold is made in five different sizes. The dimensions and wire capacity of these different sizes are shown in Fig. 100.

The No. 200 is supplied in 5-ft. lengths; the others in 10-ft. lengths. The lengths are fastened together with a coupling (Fig. 99, II) which is fastened to the wall surface

FIG. 99. I.—Wiremold metal raceway.

FIG. 99. II, III, IV, and V.—Wiremold metal raceway and support details.

with a wood screw or toggle bolt. The base of the raceway is slipped under the end of the coupling before the screw or bolt is drawn up tight. A connection cover (Fig. 99, III) snaps over the ends of the raceway, closing the joint. Each section of raceway is secured at one or two intermediate points between the couplings by means of either one- or two-hole straps (Fig. 99, IV and V) screwed or bolted to the wall surface.

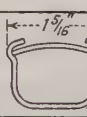
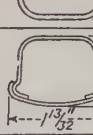
	Capacity Single conductor	Capacity Twisted pair	List price per ft.	Weight per 100 ft., lbs.
I - No.200	*2 - No.12 4 - No.16 2 - No 14 4 - No.18 *For short runs	2 - No.16 2 - No.18 2 - No.19	$0.075	18
II - No.500	1 - No 8 6 - No.16 2 - No.10 6 - No 18 2 - No.12 *2 - No 14 *3 No 14 for runs not over 30 ft. between fittings	2 - No.16 2 - No.18 3 - No 19	$0 10	32
III - No.700	1 - No. 6 4 - No.14 1 - No. 8 10 - No.16 3 - No.10 10 - No.18 4 - No.12	4 - No.16 4 - No.18 4 - No.19	$0.115	36
IV - No.1000 	3 - No. 6 9 - No.14 6 - No. 8 24 - No.16 7 - No.10 24 - No.18 9 - No.12	10 - No.16 10 - No.18 11 - No.19	$0.225	80
V - No.1100 	3 - No. 6 9 - No.14 6 - No. 8 24 - No.16 7 - No.10 24 - No.18 9 - No.12	10 - No.16 10 - No.18 11 - No.19	Base $0.150 Cover $0.085	57 26

FIG. 100.—Dimensions and wire capacity of Wiremold.

139. A comprehensive line of Wiremold fittings is manufactured by the Wiremold Co. The fittings and capping of Wiremold are finished in a neutral brown tint which blends well with most surroundings. The base of the raceway and the base plates of all fittings are given a special zinc treatment to prevent corrosion.

140. Raceways may be extended through dry walls, partitions, and floors, if they pass through in unbroken lengths.

141. Installing National Metal Raceway. Separating.—Reasonable care should be exercised in separating the backing and capping preparatory to installation. As the quickest, most satisfactory method, hooking one of the punched holes in the backing over a convenient nail or screw and drawing the capping off is recommended.

142. Cutting Raceway.—Except in cases where the backing of the raceway passes through under the fittings and is not cut, backing and capping should be cut before being separated in all cases. The manufacturer's specially designed cutting machine is the most effective tool. A hack saw may be used. Because of the light stock, hack saw blades having fine teeth and commonly known as "tube saws" are preferable. Some construction men recommend marking deeply with a file and breaking.

143. Bending Metal Raceway.—The raceway is readily bent and, with reasonable care, may be worked to any radius down to one of 4½ in. Bends must be made in all cases before backing and capping are separated.

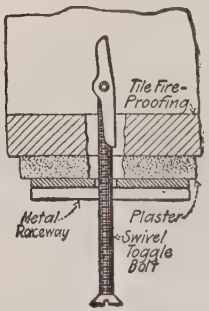


FIG. 101.—Toggle bolt being inserted.

144. Supporting Raceway.—The backing is punched and countersunk every 2 ft. for the supporting screws or bolts. The support so afforded will usually be found more than ample, but further support may be secured through either additional punching, with a special punch, or use of a metal raceway clamp. Figure 101 shows a toggle-bolt support for metal raceway. When the metal raceway is installed on uneven surfaces, such as the ceilings of old buildings, the capping has a tendency to spring away from the backing. This may be overcome by the use of two or three straps fastened over each length.

145. Loose Raceway Capping.—If the capping of the raceway is loose, it should be removed from the backing and tightened by tapping it with a mallet at points 8 in. apart on one edge only.

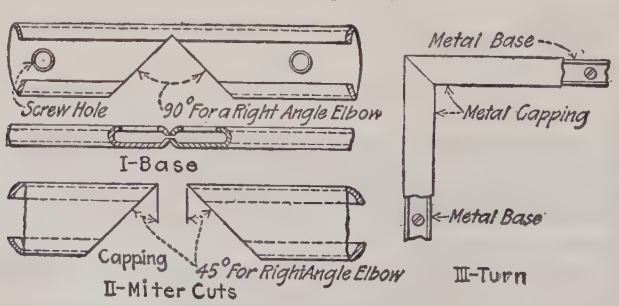


FIG. 102.—Mitered turn.

146. Metal raceway can be mitered for elbows and bends by cutting it with a hack saw. Elbows and bends thus made have the advantage that they fit into corners more closely than do the purchased fittings. Electrical conductivity is preserved by always leaving a portion of the

backing intact. Figure 102 shows how a turn can be made, and Fig. 103 shows the method for an elbow.

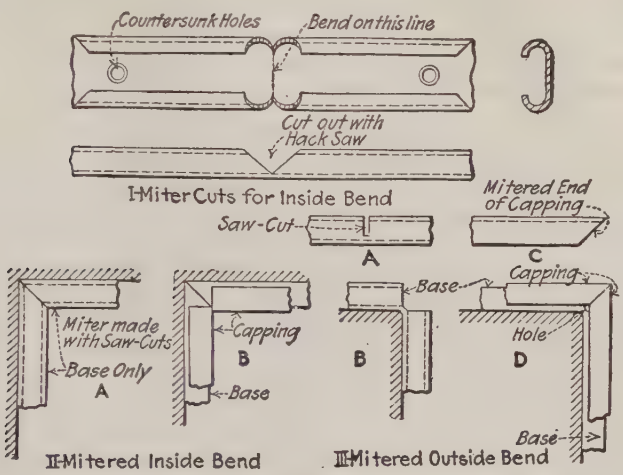


FIG. 103.—Mitered elbows.

ELECTRICAL-METALLIC-TUBING WIRING

147. Wiring employing electrical metallic tubing is used principally for extension work in existing installations and for installations where the arrangement of the branch circuits is likely to be changed frequently. The National Electrical Code allows the installation of electrical metallic tubing, either concealed or exposed, where either during construction or afterward it will not be subject to severe mechanical injury or to corrosive vapors. Electrical metallic tubing may be supported in buildings of fire-resistive construction on the face of masonry or other material of which walls or ceilings are composed. It may then be buried in the plaster finish (see Sec. **185**). Connections between lengths of tubing and between tubing and any fitting shall provide adequate mechanical strength and electrical continuity. Electrical metallic tubing should be used only for systems having a voltage of not more than 600.

148. Table 149 gives the sizes and weights of electrical metallic tubing. Since the inside diameters are the same as those for rigid metal conduit, the same tables of number of allowable wires in a conduit apply to the tubing. The wall is thinner, however, and the outside diameters of tubing are less than those for conduit. The Code requires that bends in the tubing shall be so made that the tubing will not be injured and that the internal diameter of the tubing will not be reduced. The radius of the curve of the inner edge of any field bend must be not less than that required for rigid conduit as given in Sec. **96**. The regular metallic tub-

ing has a round cross section and is made of galvanized steel. It is similar to rigid metal conduit but is made with a thinner wall of metal. Metallic tubing with an oval cross section is also made. It is called oval tubing and is designed for making underplaster extensions. It is practically the same as the oval metallic raceway mentioned in Sec. **133.** For description of oval metallic tubing refer to Sec. **186.**

149. Electrical Metallic Tubing
(Westinghouse Electric Supply Co.)

Nominal size, in.	Outside diam., in.	Inside diam., in.	Wall, in.	Wt., lb. per ft.[a]
⅜	0.577	0.493	0.042	0.268
½	0.706	0.622	0.042	0.332
¾	0.922	0.824	0.049	0.510
1	1.165	1.049	0.058	0.765
1¼	1.510	1.380	0.065	1.12
1½	1.740	1.610	0.065	1.30
2	2.197	2.067	0.065	1.65

[a] Variations from these weights must be expected in practice.

150. All outlet boxes and fittings for use with electrical metallic tubing must be of the threadless type, since owing to the thin wall it is not permissible to thread the tubing. Special threadless fittings similar to those

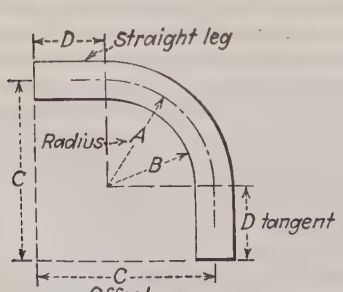


FIG. 104.—Standard radius, 90-deg. elbow.

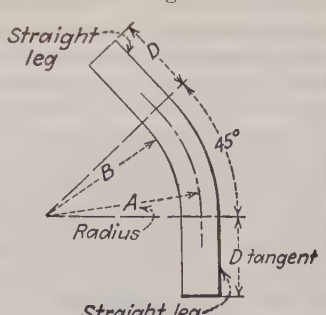


FIG. 105.—Standard radius, 45-deg. elbow.

employed for standard rigid conduit are manufactured for tubing. Standard rigid conduit fittings may be used with tubing if an adapter is employed. Sections of tubing may be joined by means of threadless couplings, which are available in steel and malleable-iron construction. Tubing is connected to outlet boxes by means of connectors. One end of the connector is made for threadless attachment to the tubing, and

the other end is threaded and supplied with a lock nut for attachment to the box through a knockout. Watertight connections can be made to the tubing with the couplings and connectors. Standard 90- and 45-deg. elbows (Figs. 104 and 105) are attached to the tubing by means of the above-described couplings. The dimensions of standard elbows are given in Sec. **151.** Watertight elbows and angle box connectors are available with the ends fitted with threadless fittings. The tubing should be supported at the same intervals as given in Sec. **85** for rigid metal conduit. Single-hole pipe straps similar in appearance to those used for rigid conduit, as shown in Fig. 45, are generally employed.

151. Dimensions of Standard Elbows for Electrical Metallic Tubing
(Westinghouse Electric Supply Co.)

Size elbow, in.	*A*, radius, in.	*B*, in.	*C*, offset, in.	*D*, tangent, in.	Weight, lb. per 100	Size elbow, in.	*A*, radius, in.	*B*, in.	*D*, tangent, in.	Weight, lb. per 100
1	5 1/16	4 9/16	10	4 3/8	100	1 1/4	6 7/8	6 1/8	4 3/4	124
1 1/4	5 1/2	4 3/4	10	4 1/2	144	1 1/2	6 7/8	6	5 1/8	147
1 1/2	6 7/8	6	10 5/8	4 1/16	180	2	8	6 7/8	5 3/4	226
2	8	6 7/8	14	5	277					

NONMETALLIC-SHEATHED-CABLE WIRING

152. Nonmetallic-sheathed cable is used for the wiring of new and old residences and for small offices and stores. It is frequently employed for extensions to existing installations and is sometimes used in small apartment houses. Nonmetallic-sheathed cable may be run either exposed on ceilings and walls or concealed in hollow partitions or between floors and ceilings. Nonmetallic-sheathed cable provides a reasonably safe and reliable wiring installation of low first cost. It must not be used in damp locations or on circuits exceeding 600 volts between conductors. It must not be installed in concrete walls or floors, or concealed in the plaster finish of walls. Most inspection departments will permit its use when installed concealed in furred walls and ceilings.

153. Nonmetallic-sheathed cable (Cable 22, Table 139, Div. 2) **is manufactured** in both two- and three-conductor cables. Each wire is insulated with rubber or thermoplastic of the same thickness as required in single wires, except that the neutral conductor may be uninsulated. Each insulated conductor is protected by means of a cotton-bound paper sheath, over which is served tough fibrous tapes. The two or three conductors are then bound together by means of an extra-heavy, triple-weight braid. The outer braid and inner sheaths are treated with a special fire- and moisture-resisting compound (see Table 159, Div. 2, for complete information on various sizes of nonmetallic-sheathed cable).

154. When nonmetallic-sheathed cable is installed exposed, it is supported directly on the walls or ceiling with straps. For three-wire cable, ordinary pipe straps are used. Standard ⅜-in. pipe straps fit Nos. 14(3), 12(3), and 10(3) sizes of sheathed cable; ½-in. pipe straps are required for No. 8(3); ¾-in. straps for No. 6(3); and 1-in. straps for No. 4(3). For two-wire cable, special flat straps are required, which are available from the different manufacturers of nonmetallic-sheathed cable. The distance between supports must not be greater than 4½ ft. and there must be a support within 12 in. of each outlet box or fitting. The cable must follow the surface of the wall or ceiling and not break from beam to beam. Whenever nonmetallic-sheathed cable is run exposed within 7 ft. of the floor, it must be suitably protected against mechanical injury. This protection may consist of a wooden or metal protecting strip or a piece of conduit or iron pipe. It is preferable to use either conduit or iron pipe, since either conduit or iron pipe must be used where the cable passes through floors. If the cable is located behind more or less fixed furniture such as refrigerators, kitchen cabinets, etc., the protection on the side walls may be omitted. Where nonmetallic-sheathed cable passes through

FIG. 106.—Method of installing nonmetallic-sheathed cable concealed in new buildings.

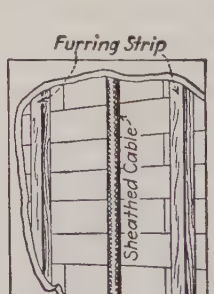


FIG. 107.—Nonmetallic-sheathed cable installed concealed in a furred partition.

floors, it must be protected by a length of iron pipe or conduit extending through the floor and to a height of at least 6 in. above the floor.

155. When nonmetallic-sheathed cable is installed concealed in new buildings, the cable is fastened to the joists or beams by means of straps

The distance between supports should not be greater than 4½ ft. In wiring finished buildings, when it is impracticable to support the cable between outlets, it may be fished from outlet to outlet in the same manner as armored cable. Where the cable is run through holes bored in studs, joists, etc., no protection is required. The holes should be bored as near to the center of the timber as possible and not less than 2 in. from the edge. The approved method of installing nonmetallic-sheathed cable in a new building is shown in Fig. 106. Most inspection departments will allow nonmetallic-sheathed cable to be run concealed in furred walls or partitions, as shown in Fig. 107. Usually it is also permitted to pass the cable directly through holes in brick or tile walls without the protection of a length of iron pipe or conduit.

156. No joints or splices should be made in nonmetallic-sheathed-cable wiring except in outlet or junction boxes, this rule applying for both exposed and concealed installation. The loop system is employed generally for concealed work. The cable is looped from outlet to outlet, and the use of junction boxes is avoided.

157. Bends in cable (National Electrical Code) shall be so made, and other handling shall be such, that the protective coverings of the cable will not be injured, and no bend shall have a radius less than five times the diameter of the cable.

158. An approved outlet box or fitting must be provided at all outlets or switch locations. The cable must be attached to the box with some

FIG. 108.—Nonmetallic-sheathed cable attached to outlet box by means of built-up clamp.

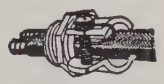


FIG. 109.—Squeeze connector for attaching nonmetallic-sheathed cable to outlet box.

form of approved device which will substantially close the opening in the box. This connection of the cable to the box may be accomplished by means of a box with a built-in clamp as shown in Fig. 108, or a squeeze connector (Fig. 109) may be employed with a box having conduit knockouts.

159. Where the National Electrical Code rules require that outlet boxes be grounded, nonmetallic-sheathed cable can be obtained with a bare grounding wire built into the cable under the outer sheath. This grounding wire should be ripped back out of the cable for 6 or 8 in., before the cable is secured to the outlet box. If outlet boxes with built-in

clamps are employed, the required contact between the box and the grounding wire is made by means of a small copper clip. The connection is made by bending the grounding wire back along the cable and fastening the clip over the grounding wire and cable. The built-in clamp in the box presses down upon the grounding clip and ensures the required contact. These copper grounding clips can be obtained from most manufacturers of nonmetallic-sheathed cable. Most squeeze connectors are provided with two washers under the screw of the clamp. The grounding wire can be secured between these two washers (Fig. 109).

160. Boxes of insulating material (Fig. 110) may be used with nonmetallic-sheathed cable instead of metal boxes. With these boxes, grounding is eliminated, and it is not necessary to use a cable containing a grounded conductor. The boxes shown in Fig. 110 are made of porcelain and may be obtained with either glazed or unglazed finish. They are used in the same way as metal boxes except that the cable is not fastened to the box but must be fastened to the building structure within

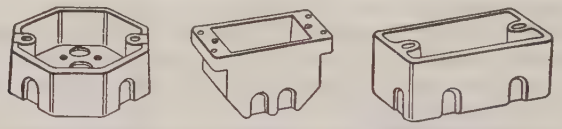


FIG. 110.—Outlet boxes of insulating material. (*General Electric Supply Co.*)

6 in. of the box. Thin sections of porcelain are knocked out to provide openings to bring the cable into the box. Nonmetallic covers must be used with devices in these boxes. The octagonal box (Fig. 110, I) is used for wall-bracket and ceiling outlets. A metal fixture stud must be bolted to the box through the holes provided for the purpose. The switch box (Fig. 110, II) is used for switches or convenience outlets with concealed wiring. The shallow switch box (Fig. 110, III) is used for switches and convenience outlets with exposed wiring.

161. A line of outlets for surface mounting with exposed nonmetallic-sheathed-cable wiring is available (Fig. 111). They are made of porcelain with an attractive brown finish. A clamp inside the case holds the cable. There are terminal screws near each end so that cables may be brought in from both ends.

162. Methods of installing nonmetallic-sheathed cable in accessible attics or roof spaces are shown in Fig. 112. When the cable is carried across the top of floor beams or across the face of rafters within 7 ft. of the floor, the cable should be protected by guard strips, as shown at *B*. If the attic is accessible only through a scuttle hole without permanent stairs or ladders, the protection is required only within 6 ft. of the edge of the scuttle hole. The cable may be supported along the sides of rafters, studs, or floor joists without any additional protection as at *D*.

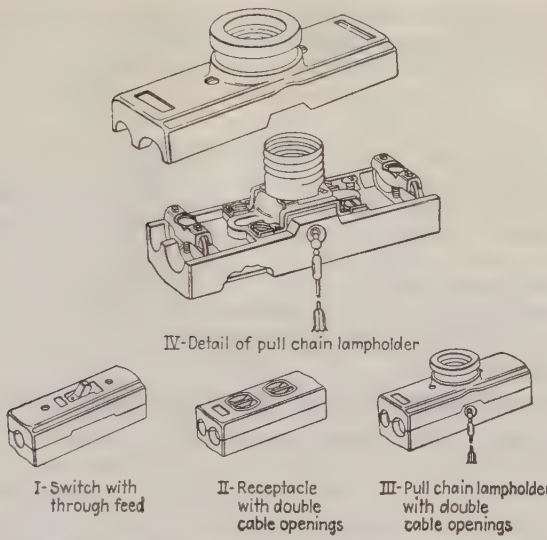


FIG. 111.—Surface outlets for use with nonmetallic-sheathed cable or armored cable. (*Pass & Seymour, Inc.*)

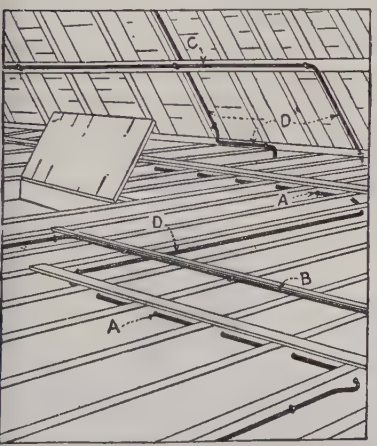


FIG. 112.—Methods of installing nonmetallic-sheathed cable in accessible attics or roof spaces.

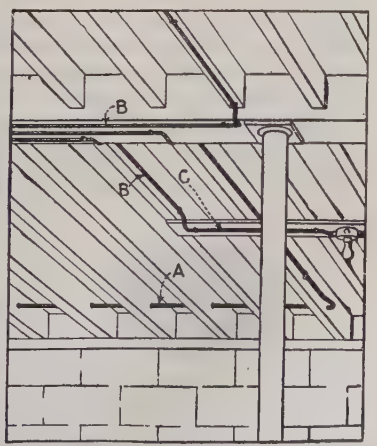


FIG. 113.—Methods of installing nonmetallic-sheathed cable in unfinished cellars or basements.

163. If thermal insulation is used in the hollow spaces of walls and ceilings in which nonmetallic-sheathed cable is installed, only approved, noncorrosive, noncombustible, nonconducting materials shall be used, and these shall be applied in a manner not apt to place a strain upon the cable, its supports, or terminal connections.

164. Methods of installing nonmetallic-sheathed cable in unfinished cellars or basements are shown in Fig. 113. The cable may be run through bored holes in the floor joists and along the sides or faces of joists without any additional protection such as running boards or guard strips, as shown at *A* and *B*. When the cable is run at angles across the bottom faces of floor joists, the cable must be supported on the underside of running boards as shown at *C*. Assemblies containing not smaller than two No. 6 or three No. 8 conductors may be secured directly on the bottom of the joists.

INTERIOR WIRING WITH SERVICE-ENTRANCE CABLE

165. Service-entrance cable of Types SE or ASE may be employed for interior wiring, installed either concealed or exposed. The construction of these cables is described in Div. 2. Cables with all the conductors rubber or thermoplastic insulated may be used for general interior wiring. Those without insulation on the grounded conductor may be used only on systems not exceeding 150 volts to ground, for range or water-heater circuits (except that the final connection to the water heater must be made with all conductors insulated), or as feeders to supply other buildings from the one containing the master service-entrance equipment. The cables with noninsulated ground conductor must have a final nonmetallic outer covering. Cables which do not have a metal armor must be installed in accordance with the rules for nonmetallic-sheathed cable as discussed in Secs. **152** to **164.** Cables which have an interlocking metal armor must be installed in accordance with the rules for armored cable as discussed in Secs. **124** to **129.**

I. Watertight screw connector.

II. Nonwatertight connector.

FIG. 114.—Box connectors for service entrance cable. (*General Electric Co.*)

166. The principal use of service-entrance cable for interior wiring is for branch circuits supplying ranges or water heaters and in farm wiring as feeders from the master service to supply the other buildings that are wired for electricity. The cable is supported on the building structure by means of single-hole cable straps made in different sizes to accommodate

the size of cable. They are similar in appearance to those used for rigid conduit. Connection to switch or outlet boxes is made by means of a connector (Fig. 114), which is made in watertight and nonwatertight types. A typical range installation is shown in Fig. 115.

NONMETALLIC SURFACE EXTENSION WIRING

167. Nonmetallic surface extensions are two-wire assemblies designed to be fastened to the wall or baseboard to supply additional convenience outlets from an existing convenience outlet. The existing outlet has to be supplied from some other approved method of wiring. Figures 116 and 117 illustrate two types of nonmetallic surface extensions. The Electrotrim (Fig. 116) consists of an assembly of two No. 14 rubber-covered wires without braid sewed into a specially treated fabric. Tacks or nails may be put through the under layer of the fabric between the wires for securing the assembly in place. The top layer of fabric forms a flap and covers the heads of the tacks and nails. Addhere (Fig. 117) consists of a high grade of rubber molding in which two No. 14 bare stranded conductors have been placed. A special cement is supplied by the manufacturer, by means of which the assembly can be firmly secured to the surface of almost any material used for interior finish. With the Electrotrim a special plug is fastened to the end of the strip and plugged into the existing outlets. With the Addhere the existing outlet is removed and remounted on a special ½-in. box extension into which the strip runs. The wires are terminated on the binding posts of the receptacle outlet. The new outlets to be supplied are of a special type for use with these materials.

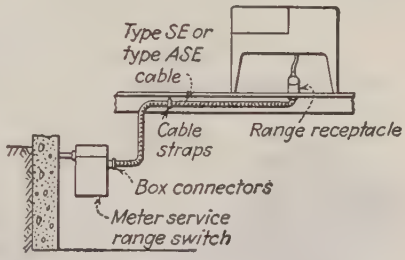


FIG. 115.—Installation of electric range wired with service-entrance cable.

FIG. 116.—Electrotrim. (*Electrotrim Inc.*)

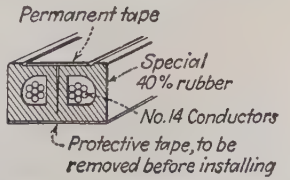


FIG. 117.—Addhere. (*Bryant Electric Co.*)

168. Nonmetallic surface extensions may be used only in dry noncorrosive-vapor locations in residences and offices for not more than 150 volts. They must not be run closer than 2 in. from the floor and must not be run outside the room in which they originate. They must be fastened at least every 8 in., except that the first fastening from the attachment

plug at the supplying outlet may be 12 in. from the plug. Since these materials are several times as expensive as armored cable or nonmetallic-sheathed cable, they should be used only for locations where the labor cost for fishing through the partition with cable is considerably greater than the labor cost for installing the surface extensions.

NONMETALLIC WATERPROOF WIRING

169. Nonmetallic waterproof wiring consists of rubber-sheathed, multiconductor cable run exposed and supported on insulators. The rubber sheathing and insulation must be composed of a waterproof rubber compound, Type RW. It is used, subject to the approval of the authority enforcing the Code, in wet locations and where subject to mildly corrosive vapors. Typical installations are breweries, ice plants, and cold-storage warehouses, for installations where the voltage does not exceed 300 between conductors or 150 to ground. The main conductors must be not smaller than No. 12, but the cable may contain a No. 14 grounding conductor, provided the circuit overload protection does not exceed 30 amp. The cable must be supported every 3 ft. with special insulating hangers (Fig. 118). All outlets must be of the vaporproof type. Conduit fittings are employed for outlets with the cable attached through an assembly which will provide a moistureproof seal (Fig. 119). When the cable passes through walls or is subject to mechanical injury, it must be enclosed in rigid conduit, electrical metallic tubing, or insulating tubing (loom), the ends of which must be sealed as in Fig. 119.

FIG. 118.—Cable hanger for nonmetallic waterproof wiring. (*Mineral-lac Electric Co.*)

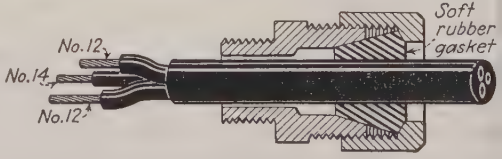


FIG. 119.—Moistureproof seal for connecting nonmetallic waterproof wiring into conduit fittings.

UNDERFLOOR RACEWAY WIRING

170. Underfloor raceway systems are used principally in office buildings for the installation of the wiring for telephone and signal systems, and for convenience outlets for electrically operated office machinery. They provide a flexible system by means of which the location of outlets may be easily changed to accommodate the rearrangement of furniture and partitions. The National Electrical Code allows their use only in buildings of fireproof construction when embedded in the concrete or in concrete fill of the floors. Their installation is allowed only in dry locations which are free from corrosive or hazardous conditions. No wires

larger than No. 0 or the maximum size approved for the particular raceway shall be installed. The voltage of the system must not exceed 600 volts. The total cross-sectional area of all conductors in a duct must not be greater than 40 per cent of the interior cross-sectional area of the duct unless the raceway contains only armored or nonmetallic-sheathed cable.

171. An underfloor raceway system consists of ducts laid below the surface of the floor and interconnected by means of special cast-iron floor junction boxes. The ducts for underfloor raceway systems are made of either fiber or steel. Fiber ducts are made in two types, the open-bottom type and the completely enclosing type. Steel ducts are always of the completely enclosing type, usually having a rectangular cross section. In the underfloor raceway system, provision is made for outlets by means of specially designed floor-outlet fittings which are screwed into

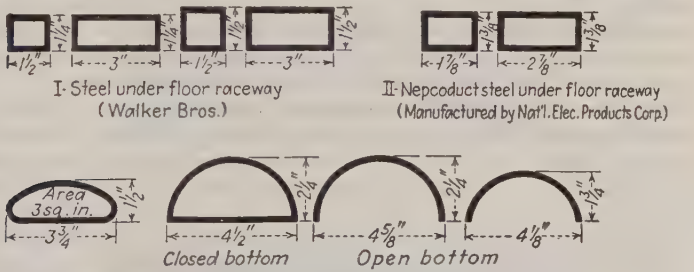


Fig. 120.—Dimensions of ducts for underfloor raceways.

the walls of the ducts. When fiber ducts are employed the duct system is laid in the floor without any openings or fittings for outlets. After the floor has been poured and finished as desired, the outlet fittings are installed at any points along the ducts at which outlets are required. The method of installing outlet fittings is described in Sec. **183.** When steel ducts are employed, provision for the outlet fittings must be made at the time that the ducts are laid, before the floor or floor fill is poured. The steel ducts are manufactured with threaded openings for outlet connections at regularly spaced intervals along the duct. During the installation of the raceway and the floor these outlet openings are closed with specially constructed plugs whose height can be adjusted to suit the floor level. The shapes and dimensions of the different types of ducts for underfloor raceways are shown in Fig. 120.

172. General Rules for the Installation of Underfloor Raceways.—In general, underfloor raceways should be installed so that there is at least ¾ in. of concrete over the highest point of the ducts. However, in offices, metal flat-top raceways not over 4 in. wide may be laid flush with the concrete if covered with substantial linoleum at least 1 in. thick

or with equivalent floor covering. When two or three raceways are installed flush with the concrete, they must be either contiguous with each other and joined to form a rigid assembly or be spaced at least ½ in. apart. Flat-top ducts over 4 in. wide and any ducts spaced less than ½ in. should be covered with at least 1½ in. of concrete. It is standard practice to allow ¾ in. clearance between ducts run side by side. The center line of the ducts should form a straight line between junction boxes. All joints in the raceway between sections of ducts and at junction boxes should be made waterproof and with good electrical contact so that the raceways will be electrically continuous. Metal raceways must be properly grounded.

173. Wires of signal or telephone systems must not be run in the same duct as wires of lighting systems. Combination junction boxes accommodating the two or three ducts of multiple-duct systems may be employed, provided separate compartments are provided in the boxes for each system. It is best to keep the same relative location of compartments for the respective systems throughout the installation.

174. The wires installed in underfloor raceways must be rubber- or thermoplastic-insulated, braid-covered, armored cable, or nonmetallic-sheathed cable. Single-braid wires are not allowed in the open-bottom type of raceway. All joints and taps must be made in the junction boxes. No joints or taps should be made in the ducts of the raceway or at outlet insert points.

175. Junction boxes for use with underfloor raceways are specially constructed cast-iron boxes. They are available in single-compartment

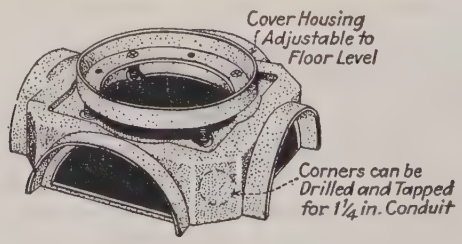


FIG. 121.—Single-compartment floor junction box.

types and in combination boxes to accommodate multiple-duct systems having two or three raceways run side by side. The general construction of the junction boxes is similar for both fiber- and steel-duct systems. A typical single-compartment box is illustrated in Fig. 121, and a two-compartment box in Fig. 122. Most boxes are equipped with leveling screws so that the boxes may be leveled up with the duct runs. The covers of the boxes also are adjustable with respect to height so that they may be accurately leveled to agree with the surface of the finished floor.

Different types of covers are available that will be suitable for the different types of floor finishes. With plain cement-finished floors a plain brass cover set flush with the floor (Fig. 123) is sometimes used. In other cases a recessed cover filled with cement is employed. For linoleum- or corkcovered floors a cover with a recess for a cork or linoleum insert is provided, as illustrated in Fig. 124. For marble or hardwood floors a recessed cover with a marble insert (Fig. 125) may be employed. With the recessed covers only a thin ring of brass

FIG. 122.—Two-compartment floor junction box for accommodating double-duct system

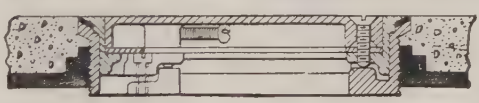


FIG. 123.—Floor junction box cover for cement-finished floor (*National Electric Products Corp.*)

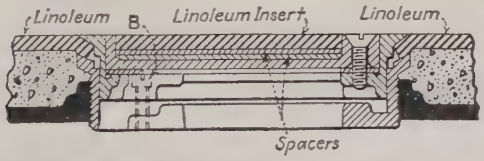


FIG. 124.—Floor junction-box cover for linoleum-covered floors. (*National Electric Products Corp.*)

shows in the finished floor, marking the location of the junction box.

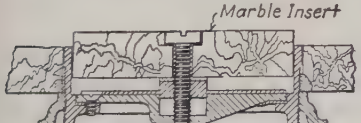


FIG. 125.—Floor junction-box cover for marble floors. (*National Electric Products Corp.*)

176. Installation of Steel-duct Raceways.—The method of installing Nepcoduct, the steel-raceway system manufactured by the National Electric Products Corp., in the concrete fill of floors is illustrated in Fig. 126. The ducts are supported by means of saddle supports, which consist, as shown in Fig. 127, of two detachable parts, a base and saddle. These supports are available for single-duct runs and in various combinations for supporting multiple-duct runs. Supports should be located not more than 5 ft. apart. After the locations of junction boxes and duct runs have been marked out, the bases of the saddle supports are fastened to the floor by means of expansion

bolts for concrete construction or by means of special toggle wires for hollow-tile work (see Fig. 126). The saddle is then assembled to the base

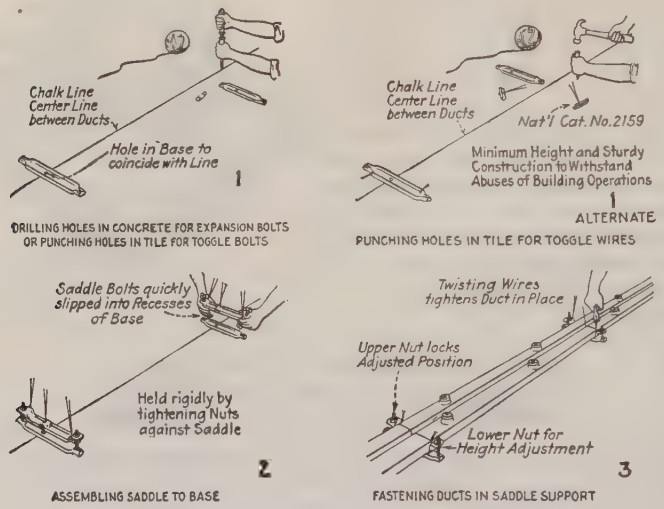


FIG. 126.—Method of installing steel underfloor raceway. (*National Electric Products Corp.*)

and the ducts fastened to the saddle by means of the tie wires. The complete raceway is then leveled and adjusted to the proper height by means of the height-adjusting bolts of the saddles and the leveling screws of the couplings and junction boxes. The adjacent sections of duct are fastened together by means of duct couplings (Fig. 128). The pointed setscrews of the couplings fasten the duct to the coupling and at the same time provide an electrical ground connection between the duct and coupling. Special fittings are available for connecting ducts and junction boxes to conduit, for connecting ducts directly to distribution cabinets, for blanking off the ends of ducts, etc.

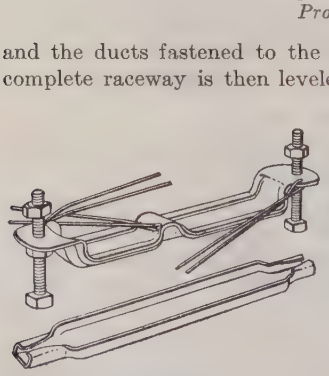


FIG. 127.—Saddle support for one small and one large steel underfloor duct. (*National Electric Products Corp.*)

177. The outlet openings in the ducts are closed by means of outlet plugs whose height may be adjusted to coincide with the floor level. A marker screw may be inserted in one plug of each 10-ft. length of duct, if it is desired to facilitate the location of the outlets. The appearance of a

duct after the installation of the floor fill with an outlet opening closed by means of an outlet plug is as shown in Fig. 129. When the floor is covered with linoleum, rubber, cork, etc., the outlets are not extended through the covering until needed. It is good practice to indicate the location of the outlet inserts by means of an escutcheon marking screw in the plugs on each side of the junction boxes, as indicated in Fig. 130. Wood or marble floors may be laid over the outlet inserts (Fig. 131), and the outlets are not extended through the finished floor until actually needed.

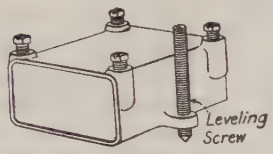


FIG. 128.—Coupling for steel underfloor raceway. (*National Electric Products Corp.*)

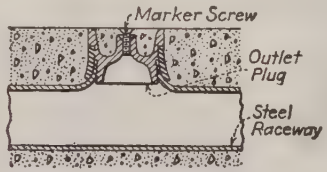


FIG. 129.—Appearance of outlet opening in steel underfloor raceway with opening closed by means of outlet plug.

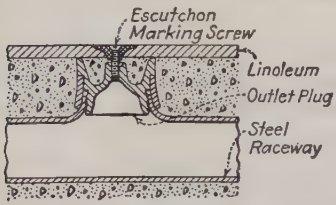


FIG. 130.—Outlet opening in steel underfloor raceway closed with outlet plug and concealed with linoleum floor covering.

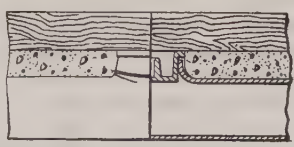


FIG. 131.—Outlet opening in steel underfloor raceway concealed by wood floor until outlet is needed. (*National Electric Products Corp.*)

178. When the raceway is installed in the concrete of the floor, the ducts are supported from the forms by means of the saddle supports, and the whole system is accurately leveled and adjusted for the proper height by means of the leveling screws and bolts on the fittings and saddle supports, before the floor is poured. In concrete-joist construction where the building codes will not allow the saddle support to be mounted directly on the concrete pans, a saddle bridge must be used to support the duct saddles. This method of installation is shown in Fig. 132.

179. Installation of Outlet Fittings in Steel-duct Raceway Systems.—When a duct outlet is to be used for service, the small amount of concrete is removed from the top depression of the outlet plug. The plug is removed by unscrewing it from the duct with a plug-removal wrench.

The removal of the plug forms a neat preformed passage through the concrete to the duct-outlet opening. The necessary wires are pulled in from the nearest junction box and threaded through the service fitting. The service fitting is then screwed into the duct outlet opening, and the floor flange adjusted.

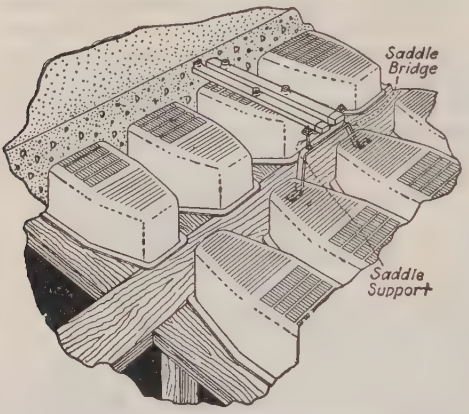


FIG. 132.—Method of supporting steel underfloor raceway in concrete-joist construction. (*National Electric Products Corp.*)

180. Installation of Completely Enclosing Fiber-duct Raceways.—Completely enclosing fiber-duct underfloor raceways may be installed in either the concrete or the concrete fill of floors in a manner similar to that described for steel-duct raceways in Sec. **176.** With the fiber-duct raceways there are no preinserted provisions for outlets. The fiber ducts are laid in the floor without any openings for outlets. After the finished floor has been laid, an outlet may be provided at any point desired along the duct runs, as described in Sec. **182.** The main component parts of a fiber-duct underfloor raceway system with their relation to the floor are illustrated by the model shown in Fig. 133. The different sections of duct are clamped together by means of a combination steel coupling and support provided with leveling screws for leveling the runs and adjusting to the proper height. The joints between sections of duct should be wrapped with a strip of 2-in. friction tape to assure a watertight joint. At junction boxes and fittings the ends of the ducts should be securely grouted into the box or fitting or sealed with pitch.

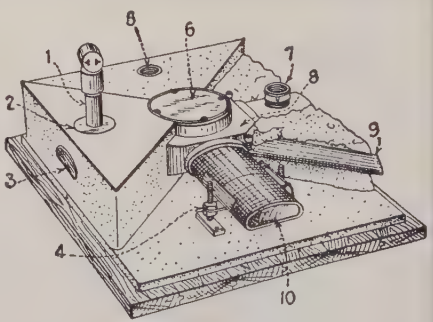


FIG. 133.—Model illustrating component parts of a completely enclosing fiber underfloor raceway installation. (*General Electric Co.*)

In some installations the raceways have been installed in the concrete

fill of floors without the use of any couplings between sections of duct and without supporting saddles. The ducts were laid and leveled directly in the cinder fill. The ducts were held in place until the pouring of the concrete-floor fill by means of a couple of shovels of cement mortar thrown around the joints in the runs.

181. Installation of Open-bottom, Fiber Underfloor Raceways.—The open-bottom type of fiber underfloor raceway can be laid only in the concrete fill of floors and not in the concrete floor proper. A smooth pad of concrete (Fig. 134) at least 1 in. in thickness, must be provided under the ducts. This pad should extend at least 1 in. on each side of the raceway. Where transverse runs of conduit are encountered, the concrete pad may be reduced to ¼ in. in thickness. At the points of crossing another duct or conduit the pad is not required, if a fitting is employed (Fig. 135) which will completely enclose and protect the wires. After the concrete pad has been laid, the locations for the ducts are marked with a chalk line, and the junction boxes and elbows set. The location of the boxes and elbows should be marked so that they may be easily relocated, if they should be knocked out of place during the laying of the duct. After the boxes and elbows are set the ducts are put in place along the chalk lines. The connection between different sections of duct and between ducts and junction boxes is made by means of slip joints. Three different methods have been employed for securing the raceway in place. One method consists of pouring a hot pitch compound along the edges of the ducts and over the joints. Another method is to throw shovelfuls of cement mortar along the edges of the ducts and over the joints. In some cases the raceway has been held in place by means of wire ties located every 2 ft. along the ducts. The tie wires were simply fastened to the concrete pad by means of a nail at each end.

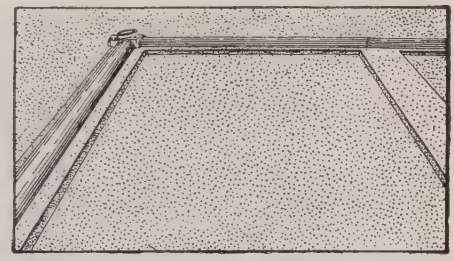


FIG. 134.—Installation of open-bottom type of fiber underfloor raceway. (*Fibre Conduit Co.*)

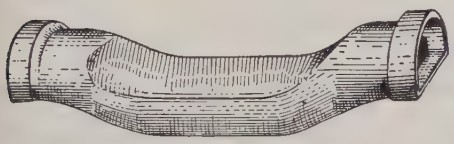


FIG. 135.—Crossunder fitting. (*Fibre Conduit Co.*)

The time required for the cutting of the duct can be greatly reduced by the use of a semicircular-bladed chisel, coinciding in shape with the inside contour of the duct, and a concave anvil which conforms in shape to the outside of the duct. Sawing of the fiber duct consumes considera-

ble time. With the use of the anvil and chisel a single sharp blow will cleanly cut the duct.

182. Installation of Outlet Fittings in Fiber-duct Raceways Systems.—The following procedure should be employed in installing an outlet fitting at any point in a fiber underfloor raceway of either the completely enclosing or the open-bottom type. The special tools provided by the manufacturers for this purpose should be used in order to ensure satisfactory workmanship.

1. Locate duct by drawing straight line from center to center of junction boxes, marker screws, or existing or abandoned outlets.

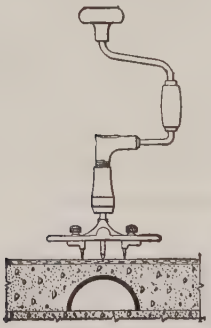


FIG. 136.—Cutting hole in floor covering. (*Fibre Conduit Co.*)

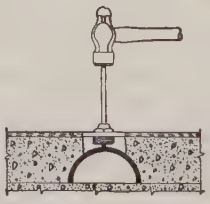


FIG. 137.—Center punching fiber duct. (*Fibre Conduit Co.*)

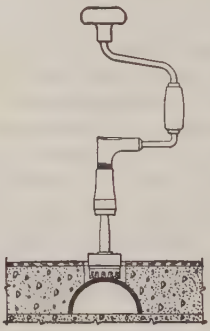


FIG. 138.—Cutting hole in fiber duct. (*Fibre Conduit Co.*)

2. Establish desired location of outlet anywhere on this line to within 8 in. of center of junction-box cover.

3. If floor is covered with linoleum, cork, etc., cut hole in covering with special cutter (Fig. 136).

4. Chip out concrete, until top of duct is exposed. The hole should be made large enough to allow the special duct-cutting tool to reach the duct.

5. Clean out hole with blower.

6. If floor is covered with linoleum, cork, etc., mark drilling center on duct so that hole in duct will be drilled concentrically with hole cut in floor covering. The manufacturers of fiber-duct raceways furnish special centering punches for this purpose (Fig. 137).

7. Drill hole in duct with special duct-cutting tool (Fig. 138). These tools are so constructed that they prevent the chips from falling into the duct. The best results in drilling the duct can be obtained by applying only a light pressure on the brace and using a special cutting grease on the blade.

8. Select outlet insert of proper length for depth of concrete over duct.

9. Screw insert into duct, until insert is flush with concrete-floor surface.

10. Thoroughly grout insert in with mixture of Portland cement and sand (Fig. 139). Do not use plaster of paris.

11. If floor is covered with linoleum or similar type of floor covering, screw floor flange into insert, until top of flange is flush with floor.

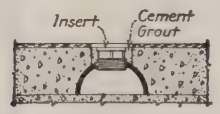


FIG. 139.—Outlet insert. (*Fibre Conduit Co.*)

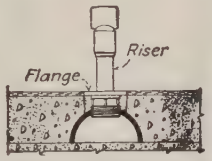


FIG. 140.—Completed outlet in fiber underfloor raceway system. (*Fibre Conduit Co.*)

12. Pull in necessary wires from the nearest junction box and thread them through outlet riser.

13. Screw riser into outlet insert or floor flange (Fig. 140).

183. Layout of Underfloor Raceway Systems.—A very simple layout for an underfloor raceway system, called the single run-around, is shown

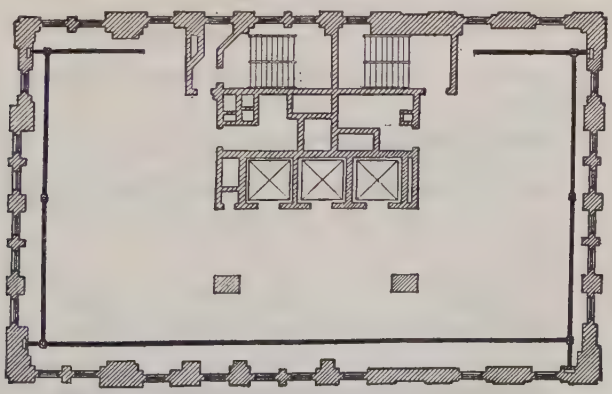


FIG. 141.—Single run-around layout for underfloor raceway.

in Fig. 141. Such a layout provides only the minimum of flexibility in the location of outlets. It is satisfactory for certain types of buildings, when the installation cost must be limited and the desks will be located only around the side walls. This layout will provide outlets only for telephone and signal systems. A similar layout is shown in Fig. 142. This layout, having two separate raceways, provides outlets for elec-

trically operated office machines from one raceway, and outlets for telephones and signal systems from the other raceway.

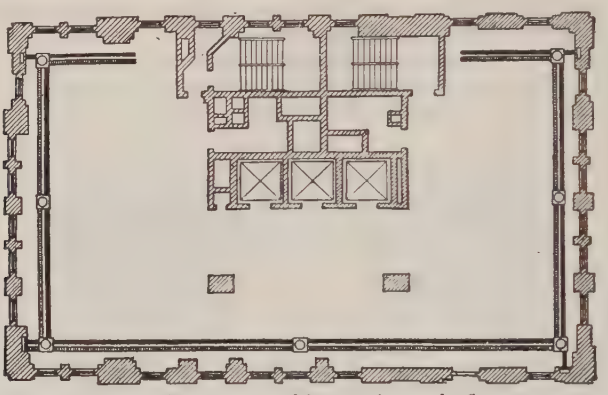


FIG. 142.—Double run-around layout for underfloor raceway.

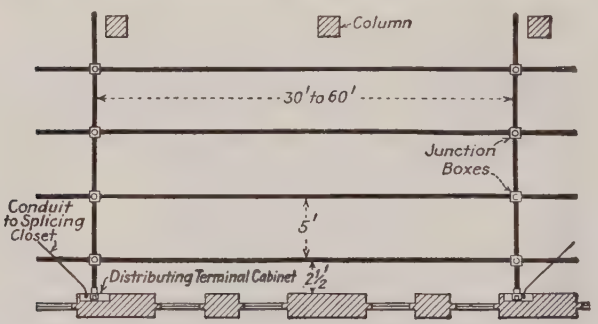


FIG. 143.—Single-grid layout for underfloor raceway.

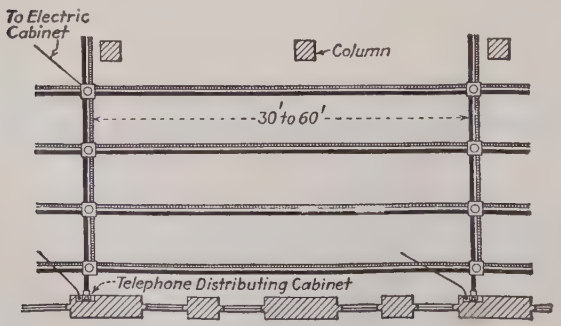


FIG. 144.—Double-grid layout for underfloor raceway.

184. In order to provide greater flexibility in the possible location of outlets over the entire area than is accomplished with the run-around layouts, grid layouts are employed. A typical single-grid layout is shown in Fig. 143, and a double grid in Fig. 144. The extent of the flexibility provided for the location of outlets depends upon the distance between parallel duct lines. For maximum flexibility the parallel lines of duct should be located approximately 5 ft. apart with the outside runs located 3 ft. from the outside walls. The distance between rows of junction boxes should be from 20 to 60 ft., depending upon the estimated number of outlets that will be required at any one time between junction boxes. Each outlet must be supplied by a separate circuit from the junction box to the outlet.

UNDERPLASTER EXTENSION WIRING

185. Underplaster Extensions.—It is frequently necessary to change the location of branch lighting and appliance circuits in order to accommodate relocation of outlets. The National Electrical Code allows such changes to be made in buildings of fire-resistive construction by means of extensions to the existing branch circuits buried in the plaster of walls and ceilings. The wires for these underplaster extensions may be run in rigid or flexible conduit, armored cable, metal raceways, or electrical metallic tubing. The general rules of construction required for the method employed should be followed. These underplaster extensions are made in the following manner. A groove is cut in the plaster finish wide enough to allow the installation of outlet boxes and the conduit, armored cable, metal raceway, or tubing. The conduit, armored cable, raceway, or tubing and outlet boxes are laid in this groove and fastened to the face of the masonry or other material of which the walls or ceiling are composed. The groove is then replastered, the wiring being concealed in the plaster finish.

186. Oval tubing which is a special form of electrical metallic tubing or metal raceway is manufactured principally for use in underplaster extension wiring. It is a rigid tube formed from sheet steel and has a flattened-oval cross section. The approximate outside dimensions are $1\frac{3}{32}$ in. high and $3\frac{1}{32}$ in. wide. It is manufactured in 10-ft. lengths. Its shallow height makes it particularly adaptable for underplaster extension work. It can be installed without channeling the underlying tile, cement, or brick of a wall or ceiling, since plaster of ordinary thickness is sufficient to cover it completely. Oval tubing will accommodate three No. 14 wires. A special line of outlet boxes and fittings has been developed so that oval-tubing wiring may take care of almost any wiring situation The tubing is supported on tile walls and ceilings by means of special wire toggles set into small holes in the tile or by means of short tie wires which are fished through small holes drilled in the tile on each side of the duct. With concrete construction oval tubing is fastened to

the slab with special straps supported by screws in expansion sleeves set in the concrete.

187. Armored cable with an oval cross section is made to meet the needs of underplaster extensions. It is made only in two-conductor cables and has a thickness across the flat portion of approximately $\frac{7}{16}$ in. The conductors consist of either two No. 14 or two No. 12 wires. Straight and elbow fittings are available for connecting oval armored cable to outlet boxes and for coupling together lengths of cable. The cable is supported with especially designed two-hole straps.

188. Single-conductor armored cable or single conductors in $\frac{5}{16}$- or $\frac{3}{8}$-in. metal conduit or tubing may be used for underplaster extensions even with a-c systems. Such an extension must be confined to the floor on which it originates. Single conductors up to No. 8 American wire gage may be used in $\frac{3}{8}$-in. conduit. This size of conduit may frequently be concealed in plaster where the $\frac{1}{2}$-in. conduit would be too large.

WIREWAY WIRING

189. Wireways may be used in exposed dry locations in industrial buildings, theaters, or garages. They must not be used where subject to severe mechanical injury or corrosive vapors or in hoistways, any hazard-

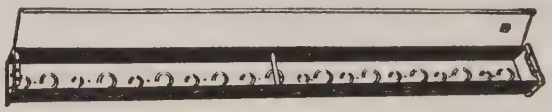


FIG. 145.—A length of wireway with hinged cover.

ous location, or storage-battery rooms. Their principal application is for the installation of mains and feeders in industrial plants or other locations where a flexible means of supplying branch circuits is advantageous or where a large number of wires must be located in one run. A type made by one manufacturer and called Square Duct is illustrated in Fig. 145. Three sides are provided with closely spaced knockouts for conduit or armored-cable attachment. The fourth side consists of a hinged cover which may be opened for installing wires and making splices. The lengths are coupled together with nuts and bolts which secure a sheet-metal hanger (Fig. 146, I) between the flanged ends of the duct sections for supporting the duct. Mains and feeders are run in the wireway with taps for branches taken off at the most convenient point through rigid or flexible conduit or armored cable, connected to the wireway through the knockouts. Square plates are obtainable (Fig. 146, IV) for closing the ends of the duct. Junctions of wireways are formed by using a junction box or a tee (Fig. 146, II and III). The wireways are made in two sizes: $2\frac{1}{2}$ in. square and 4 in. square. Conductors up to 500,000 cir. mils may be used in wireways, provided that the sum of the cross-

sectional areas of all the conductors at any cross section does not exceed 20 per cent of the interior area of the wireway. Splices and taps may be located within the wireway, provided the hinged cover is left accessible. The conductors including the splices must not fill the wireway to more than 75 per cent of its area. The wireway must not contain more than 30 conductors at any point except for signaling circuits or for control conductors between a motor and its starter, used only for starting duty. Wireways must be supported every 5 ft. and for that reason are usually made in 5-ft. lengths. Two-foot lengths are available, however, for completing the duct to the exact length required. By special permission of the authority enforcing the National Electrical Code, the distance between supports may be increased to 10 ft. in case closer supports are not feasible. An unbroken length of wireway may extend through a dry wall.

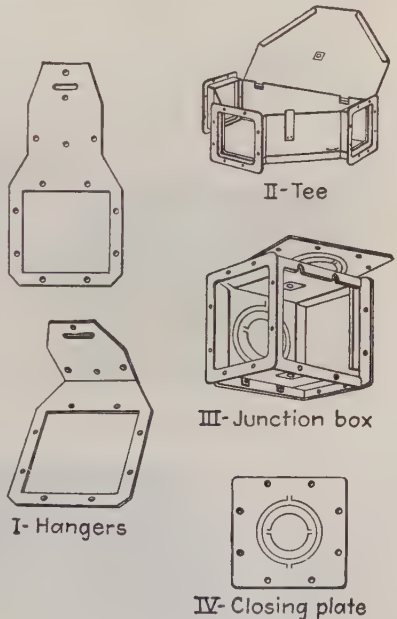


Fig. 146.—Fittings for Square Duct. (*Square D Co.*)

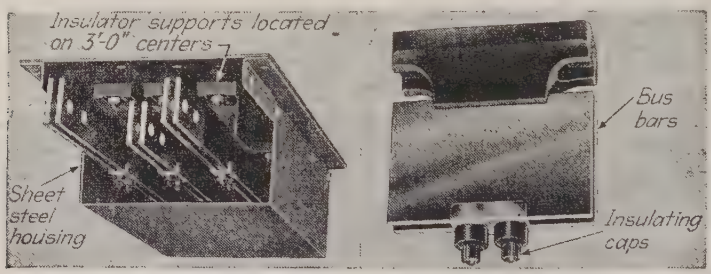
BUS-WAY WIRING

190. Bus way is one of the newer developments in interior wiring systems. It provides a flexible power-distribution system for distributing power to motors and, in some cases, lights, in industrial buildings. This method provides a flexible method of connecting branch motor circuits to the mains so that the location of the branch taps may be readily and economically changed to suit the conditions of rearrangement of machines. This system finds a wide field of use in industrial plants where the layout of the machines must be continually changed in order to meet changing manufacturing conditions. For installations of this type, although the first cost may be somewhat greater than for other methods of wiring, the saving derived from its flexibility in the relocation of machines without additional wiring expense soon overbalances the additional first cost. With the flexible bus-way method of wiring there is no ripping out and scrapping of old material and installing of new to meet the new layout conditions. Bus way may be installed in exposed dry locations for circuits of not more than 600 volts. It may also be

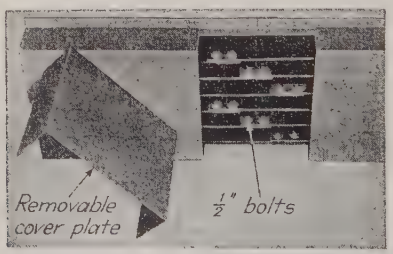
used as risers and feeders in office buildings of fire-resistive construction. It must not be used where it will be subjected to severe mechanical injury or corrosive vapors, or in hoistways, in any hazardous location, in storage-battery rooms, or in damp locations unless specially approved for the purpose. Unbroken lengths of bus way may extend through dry walls.

191. Bus ways consist of bus bars mounted in a sheet-metal enclosure or trough. They are made in three main types for voltage up to 600 volts: (1) without plug-in provision, (2) with plug-in provision, at fixed intervals, and (3) with movable trolley contacts.

192. Bus ways without plug-in provisions are used as main-feeder runs from the main power-supply location for a building, such as from



I. Buss-wa section. II. Insulator support.



III. Joint between two Buss-wa sections.

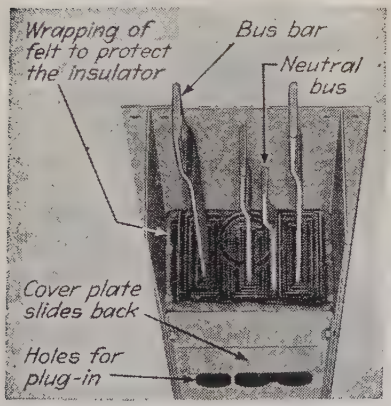
FIG. 147.—Buss-wa details. (*Trumbull Electric & Manufacturing Co.*)

the secondary of transformers to switchboards and from switchboards to distributing centers. One type called Buss-wa is shown in Fig. 147, I. It is made for systems of from two to nine poles, each pole of the Buss-wa consisting of one or two bus bars, depending upon current capacity required. Table 194 gives the dimensions and weights of Buss-wa. The bus bars, rated on the basis of 1,000 amp. per sq. in., are available in 250- to 15,000-amp. sizes. The bus bars are supported by individual insulators made of a special refractory material which will not carbonize (Fig. 147, II). Insulating caps are used over the ends of the bus-bar supporting studs to prevent accidental contact with the housing. Buss-wa comes in 10-ft. lengths which are coupled together by overlapping

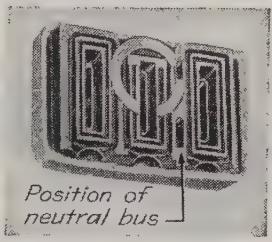
the bus bars and joining them with ½-in. bolts (Fig. 147, III). A sheet-steel cover plate fits over the joint. Adapter switches, panel boards, and circuit breakers are available for fastening directly to the bus way, as shown in Fig. 157.

193. A bus way with plug-in provision and known as Flex-A-Power is shown in Fig. 148. It is made for systems of from two to four poles.

I. Length of Flex-A-Power with end plate in place.



II. Detail of end of Flex-A-Power section.

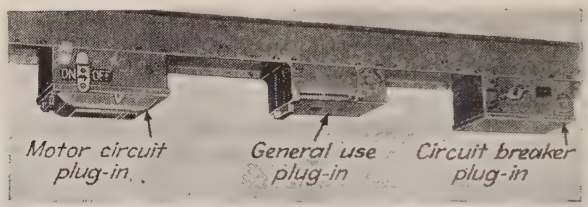


III. Insulator detail.

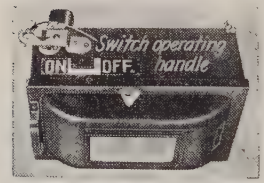
FIG. 148.—Flex-A-Power details. (*Trumbull Electric & Manufacturing Co.*)

Each pole consists of a single bus bar rated at 250, 375, 500, 750, or 1,000 amp.

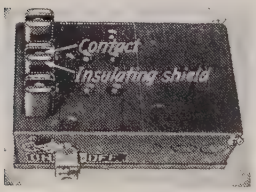
Table 196 gives the dimensions and weights of Flex-A-Power. The bus bars are supported in slots in porcelain insulators (Fig. 148, III) spaced every 30 in. along the trough. Every 12 in. in the bottom cover plate there is a set of holes for insertion of plug-in connections. Each set of holes is normally covered by a sliding cover plate, which may



I. Assembly of plug-ins on length of Flex-A-Power.



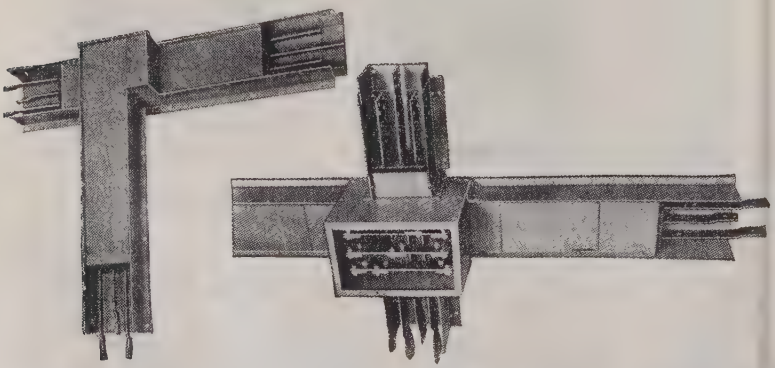
II. Front view of plug-in.



III. Rear view of plug-in.

IV. Interior of plug-in.

FIG. 149.—Plug-ins for Flex-A-Power. (*Trumbull Electric & Manufacturing Co.*)



I. "T"-type Flex-A-Power connection.

II. Flex-A-Power crossover connection.

FIG. 150.—Junctions for Flex-A-Power systems. (*Trumbull Electric & Manufacturing Co.*)

be loosened by a quarter turn of two setscrews. The plug-ins (Fig. 149) are a special type of fused switch or circuit breaker which have contacts (Fig. 149, IV) which engage on the bus bars. The insulating shields prevent an accidental connection between a contact and the frame of the bus way in the insertion and removal of the plug. Figure 149, I, shows the three types of plug-ins assembled on a length of the bus way. The motor-circuit type has a fused switch of the motor-circuit type which will break the stalled-rotor current of a motor. The switch may be operated while the plug-in contacts remain in contact with the bus bars. The general-use one is fused but does not have a switch. When the cover is opened to remove the plug-in from the bus a set of auxiliary contacts will break the rated current of the plug-in before the main contacts leave the bus. The third type contains a thermal, time-limit circuit breaker which may be operated while the plug-in remains in position on the bus. The fused plug-ins are obtainable in ratings of 30, 60, 100, and 200 amp. The circuit breaker may be obtained with the usual circuit-breaker ratings in 50-, 100-, and 225-amp.-frame sizes. Hook sticks are made in a number of different lengths for operating the switch arms from the floor. Sections of Flex-A-Power are bolted together in the same manner as explained for Buss-wa. Tee connections may be made as shown in Fig. 150, I, and crossovers of one bus under another either tapped or not tapped, as shown in Fig. 150, II.

194. Dimensions and Weights of Buss-wa

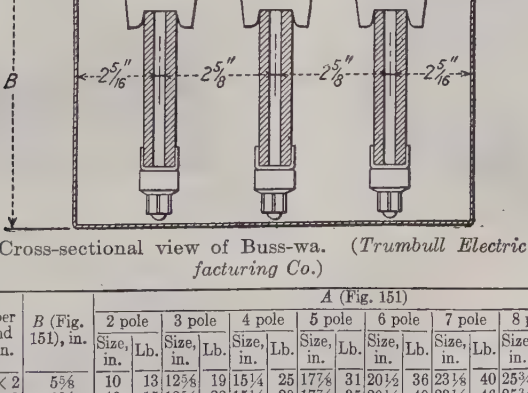
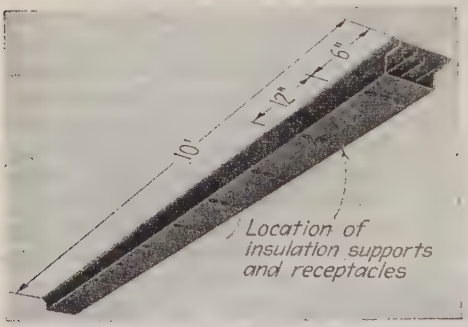


FIG. 151.—Cross-sectional view of Buss-wa. (*Trumbull Electric & Manufacturing Co.*)

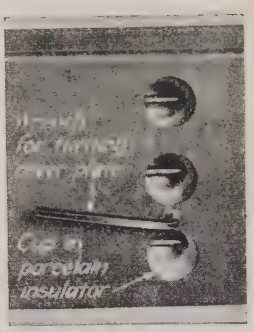
Capacity, amp.	Bars per leg and size, in.	*B* (Fig. 151), in.	*A* (Fig. 151)															
			2 pole		3 pole		4 pole		5 pole		6 pole		7 pole		8 pole		9 pole	
			Size, in.	Lb.	Size, in.	Lb.	Size, in.	Lb.	Size, in.	Lb.	Size, in.	Lb.	Size, in.	Lb.	Size, in.	Lb.	Size, in.	Lb.
500	1; ¼ × 2	5⅝	10	13	12⅝	19	15¼	25	17⅞	31	20½	36	23⅛	40	25¾	50	28⅜	55
750	1; ¼ × 3	6⅝	10	15	12⅝	22	15¼	29	17⅞	35	20½	40	23⅛	46	25¾	56	28⅜	61
1,000	1; ¼ × 4	7⅝	10	18	12⅝	26	15¼	34	17⅞	40	20½	45	23⅛	52	25¾	62	28⅜	68
1,500	2; ¼ × 3	6⅝	10	22	12⅝	31	15¼	38	17⅞	45	20½	54	23⅛	63	25¾	70	28⅜	75
2,000	2; ¼ × 4	7⅝	10	28	12⅝	36	15¼	47	17⅞	54	20½	61	23⅛	68	25¾	75	28⅜	82
2,500	2; ¼ × 5	8⅝	10	35	12⅝	45	15¼	55	17⅞	65	20½	75	23⅛	82	25¾	90	28⅜	93

For larger sizes refer to the Trumbull Electric & Manufacturing Co.

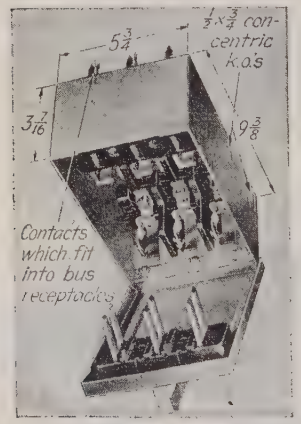
195. A smaller size of Flex-A-Power made for two- or three-pole construction, rated for 125 amp. and called "125" Flex-A-Power, is shown in Fig. 152. In this type the bus bars are supported every 12 in. with porcelain blocks which have cup-shaped openings in the bottom. There are holes in the cover plate over these openings. An interior



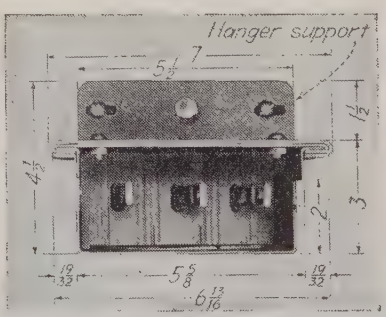
I. Length of "125" Flex-A-Power.



II. Detail of receptacles.



III. Flex-A-Plug.



IV. Cross-sectional view of bus enclosure.

FIG. 152.—"125" Flex-A-Power.

metal cover which is turned with a special socket wrench, as shown in Fig. 152, II, covers the openings when not in use for a plug. Fused plugs are available in 30-amp. and convertible 30/60-amp. ratings. These plugs are inserted on the bottom of the bus way with plug contacts fitting onto the bus bars through the porcelain-cup openings.

196. Dimensions and Weights of Flex-A-Power

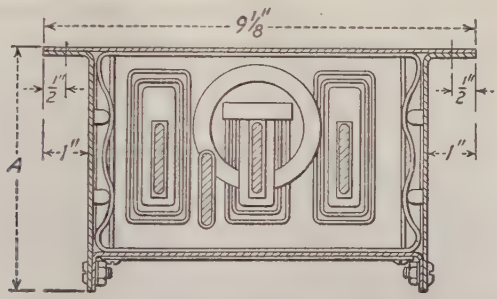


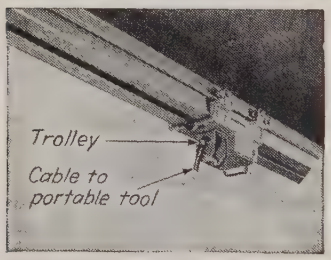
FIG. 153.—Cross-sectional view of Flex-A-Power. (*Trumbull Electric & Manufacturing Co.*)

Capacity, amp.	Bars per leg and size, in.	Size of neutral, in.	*A* (Fig. 153), in.	Approx. weight, lb. per 10-ft. length		
				2 pole	3 pole	3 phase, four wire
250	1; ¼ × 1	1; ¼ × 1	4 1/32	80	90	103
375	1; ¼ × 1½	1; ¼ × 1	5 1/32	93	108	125
500	1; ¼ × 2	1; ¼ × 1	5 1/32	108	128	150
750	1; ¼ × 3	1; ¼ × 1½	7 1/32	125	150	190
1,000	1; ¼ × 4	1; ¼ × 2	7 1/32	145	175	228

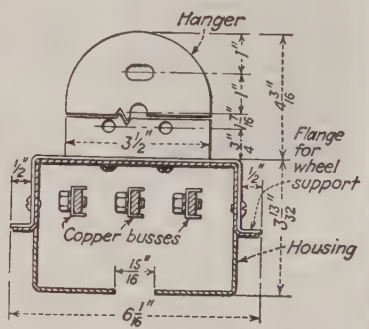
197. Dimensions of Flex-A-Power Plugs

Capacity, amp.	Width, in.	Length, in.	Depth, in.
General-use Type			
30	6¾	11⅝	4 7/16
60	6¾	11⅝	4 7/16
100	6¾	15¾	4 7/16
Motor-circuit Type			
30	6⅞	11⅝	4 13/16
60	6⅞	11⅝	4 13/16
100	11	20⅜	4 11/16
200	11	22⅞	4 11/16
Circuit-breaker Type			
50	6⅝	11⅝	5 7/16
100	6⅝	11⅝	5 7/16
225	9 11/16	23½	7¼

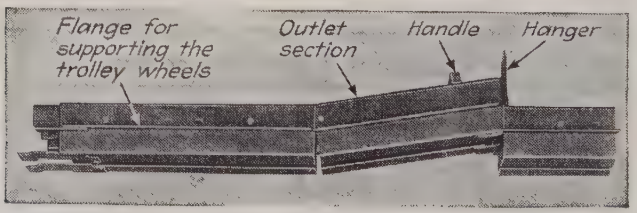
198. Trolley-Closur is a bus-way system for installations requiring overhead trolley wires. In certain industries, as, for example, in automobile-body plants, overhead trolleys are required for supplying energy to portable tools. The Trolley-Closur system consists of a steel housing containing bare channel-shaped copper conductors (Fig. 154). Power is tapped from the trolleys by means of specially designed collectors with provision for fuses in each branch wire. The collectors can be inserted



I. Trolley-Closur with trolley.



II. End view.



III. Method of installation or removal of trolley collector.

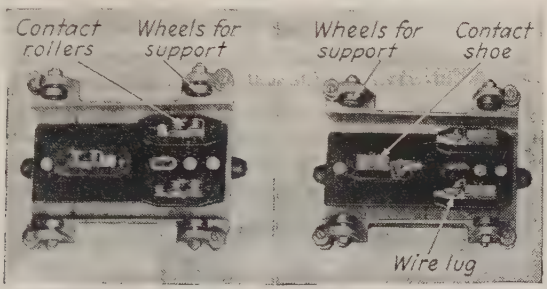
FIG. 154.—Trolley-Closur. (*Trumbull Electric & Manufacturing Co.*)

or removed at outlet points on the trolley. This system provides an enclosed safety overhead trolley system.

There are three channel conductors which may be connected to any one of several different power-supply systems:

1. 110/220 volts, three wire, single phase.
2. 400 volts, two wire, single phase.
3. 220 volts, three wire, three phase.
4. 440 volts, three wire, three phase.
5. 550 volts, three wire, three phase.

The power-supply wires are brought to the conductors through a feed-in box which may be located on the top near one end of any 10-ft. section.

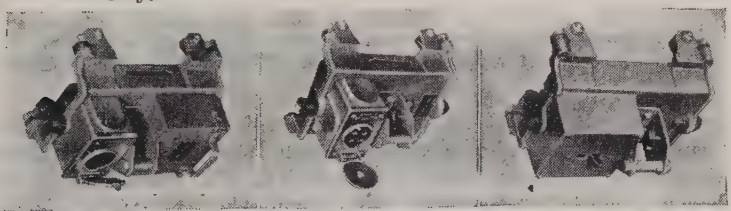


I. Trolley collector showing contact-roller assembly.

II. Heavy-duty trolley collector showing shoe-type assembly.

III. Fusible trolley collector with tool hanger, 30 amp. maximum, 250 volts only.

IV. Fusible trolley collector, 30–60 amp., 600 volts.



V. Fusible trolley collector with single lock-type receptacle.

VI. Nonfusible trolley collector with single lock-type receptacle.

VII. Trolley collector with tool hanger and thermostatic tumbler switch for portable tool protection.

FIG. 155.—Types of trolleys for Trolley-Closur. (*Trumbull Electric & Manufacturing Co.*)

The capacity of the channel conductors is 100 amp., but the capacity of the trolley system may be made much greater than that by using several feed-in points.

The trolley runs on four wheels which bear on the flange on the sides of the overhead housing (Fig. 154, II). The current collectors are mounted on an insulating plate on the top of the trolley and are held against the underside of the copper busses by individual coil springs. There are two types of contacts which are made of copper and graphite impregnated with oil: (1) a double roller rated at 30 amp. (Fig. 155, I) and (2) a contact shoe rated at 60 amp. (Fig. 155, II). The trolley collectors are made in several different types to suit various types of branch circuits. Figure 155, III shows one with 30-amp., 250-volt cartridge fuses for branch-circuit protection. For loads up to 60 amp

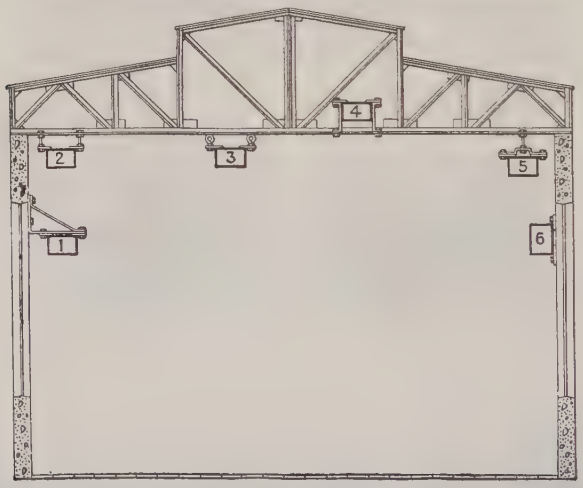


FIG. 156.—Methods of supporting bus ways. (*Trumbull Electric & Manufacturing Co.*)

and for 600 volts, the 30/60-amp., convertible-fuse unit of Fig. 155, IV is used. They may also be obtained with two-, three-, or four-pole locking-type receptacles, fused or unfused (Fig. 155, V and VI), for use where it is desired to remove the portable cord when the trolley is not in use. Figure 155, VII illustrates a trolley containing a switch with thermostatic overload protection for the motor on the tool. The trolley collectors are inserted on the system by lifting up a hinged outlet section (Fig. 154, III) and slipping the collector on the end so that the contacts bear against the bottom of the channels and the wheels ride on top of the flange. Then the outlet section is dropped back into position. This operation may be performed without de-energizing the conductors.

A lighter weight trolley system rated at 50 amp. made by the Bull Dog Electric Products Co. has an outlet-box-type trolley, which in addition to supplying small tools may be used to support lighting fixtures.

The advantage claimed for this system is that the lights may be moved along with the tools. This is a decided advantage in locations where normally only rough work requiring low values of illumination is performed. Then occasionally, when finer detailed work is set up, the lights can be moved closer together and the illumination built up to higher values for that section of the room. This is especially recommended

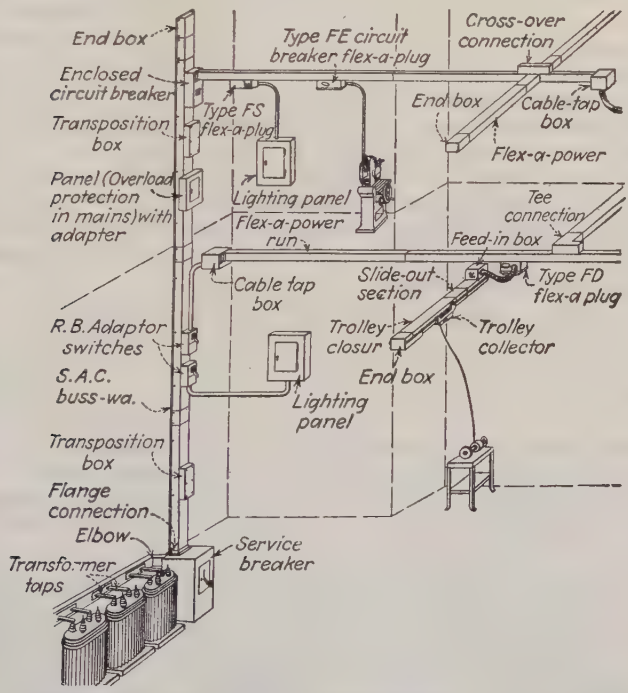


FIG. 157.—Typical layout of bus-way feeder distribution system. (*Trumbull Electric & Manufacturing Co.*)

or mercury-vapor lighting where the lamp wattage cannot be easily varied, since a given transformer will take only one size of lamp.

199. Bus ways may be supported from the framework of the building in a number of different ways, using standard structural members such as steel bars, angles, rods, or messenger cable. Figure 156 shows some suggested locations, but each installation has to be designed individually according to the design of the building. The National Electrical Code requires supports to be located every 5 ft., except that by special permission the distance may be lengthened to 10 ft.

200. The supply circuit for any of the bus-way systems may be brought in at the end or at any of the section junctions, using a special box, which forms a splicing chamber. The cable lugs of the supply circuit are bolted to the bus bars.

201. Branch circuits are taken out through the knockouts in the plug-in boxes, using armored cable, flexible conduit, or rigid conduit. If the vertical length of the branch circuit is more than a few feet it is desirable, when using cable or flexible conduit, to loop the cable or conduit up over the bus way before bringing it down. This puts the weight of the cable on the bus way instead of on the connector to the box.

202. A composite typical layout in Fig. 157 shows the function of the various types of bus ways. Starting at the building-service transformers, Bus-wa carries the feeder circuit to the service circuit breakers and up through the building. Mains are taken off through adaptor switches to supply lighting panel boards and Flex-A-Power runs. A Trolley-Closur is fed from a Flex-A-Plug on the Flex-A-Power bus. Fixed motor-operated tools are supplied from the Flex-A-Power bus, and portable tools from the Trolley-Closur.

CELLULAR-METAL-FLOOR-RACEWAY WIRING

203. Cellular-metal-floor raceways are formed by employing for the floor construction of the building structural members made of corrugated sheet steel. Six types of cellular steel floor as made by the H. H. Robertson Co. of Pittsburgh, Pa., are shown in Fig. 158. Type I is the funda-

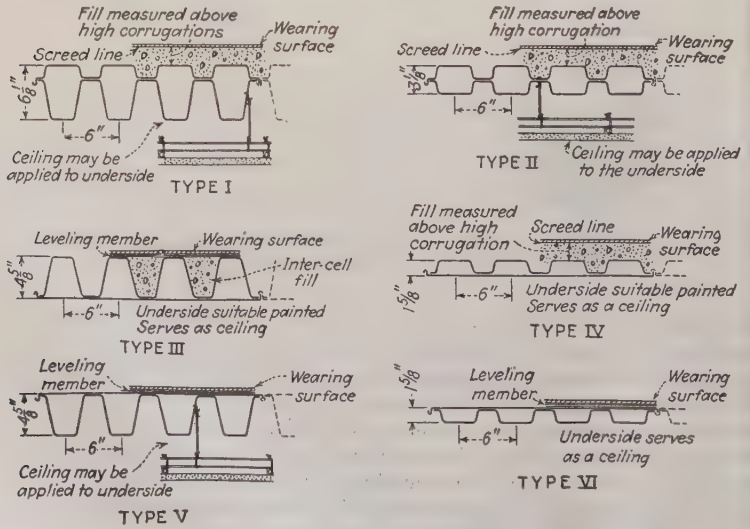


FIG. 158.—Types of cellular steel floors. (*H. H. Robertson Co.*)

mental type used for buildings with average floor loadings and with beam spans of 12 to 16 ft. Type II is formed by using both top and bottom corrugations of the same size as the top of Type I and is for somewhat lighter loads. Both of these types are intended for use with a concrete fill on top to form the rough floor and with the ceiling of the floor below suspended from the underside. Type III is formed by using the bottom corrugations from Type I as the top unit, with a flat plate as the bottom unit. The flat plate serves directly as a ceiling, and the floor is formed by filling in the top corrugations with concrete. Type V is formed by inverting Type III and not using any concrete. Types IV and VI are for very light loads and are formed from the top unit of Type I, with a flat metal plate in a manner similar to the way Types III and V were formed.

204. The cells which are not filled with concrete form the raceways for wiring and piping. In all the types the cells are 6 in. apart on centers, and the members are manufactured four cells wide with varying lengths to suit the span between beams. The cells are cross connected by headers formed over the beams in the space left between adjacent lengths of flooring. By using headers connected to alternate cells, one raceway system may be formed for signal wires and another for power wires, with both systems kept entirely separate from each other. If any cells are used for piping, those cells must not be interconnected to the electrical raceway system.

205. In forming these floors, close cooperation is required between the structural and the electrical workmen. The structural men lay the floor members across the spans from beam to beam, fastening them to the beams and leaving about 4½ in. of space on top of the beams

FIG. 159.—Laying cellular steel floors. (*H. H. Robertson Co.*)

between the abutting ends of the floor members (Fig. 159) for formation of the header.

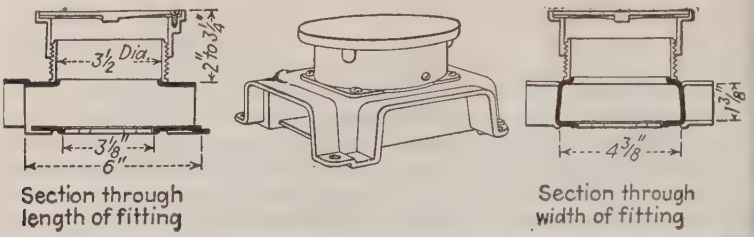


FIG. 160.—Access unit for cellular metal floors which have concrete fill. (*H. H Robertson Co.*)

The raceway headers are formed by the electrical workmen. For floors of Types I and II of Fig. 158 the header is formed in the space shown in Fig. 159 on top of the floor beams. A line of cells which is to form a raceway is interconnected at the ends of the sections by locating an access unit (Fig. 160) between the open ends of the aligning cells of adjacent sections.

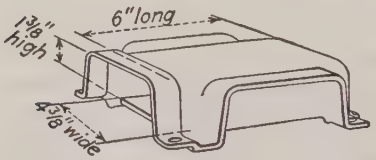


FIG. 161.—Connecting header unit.

The other cells are closed off with connecting units (Fig. 161) so as to form a continuous header across the beam to the raceway line of cells.

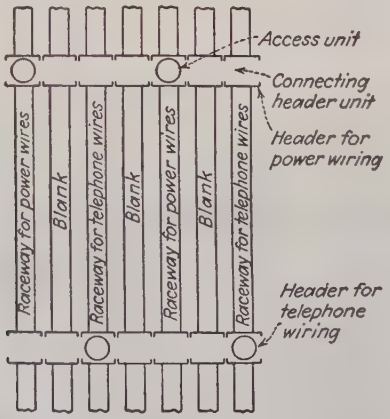


FIG. 162.—Method of forming separate headers for power and for telephone wiring.

Where one raceway system is to be built for power wiring and another for telephone wiring, the header for one system is built on one junction

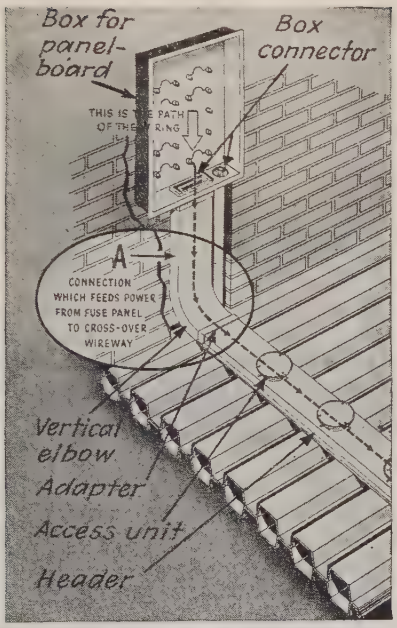


FIG. 163.—Connection of cellular-metal-floor header to panel board. (*H. H. Robertson Co.*)

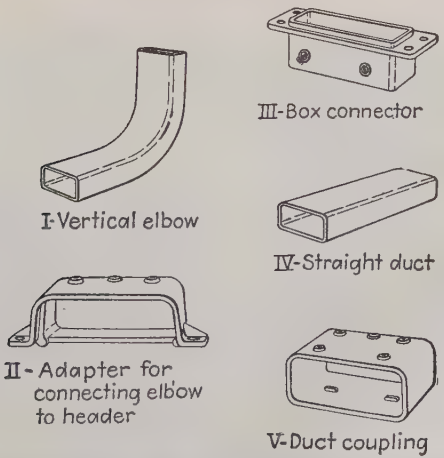


FIG. 164.—Fittings for connecting cellular-metal-floor header to wall panel board. (*H. H. Robertson Co.*)

of floor beams and the header for the other system on another junction (Fig. 162). The wires for one system will pass through the lower portion of its cells under the header for the other system. The joints at the edges of the header units are sealed with a cold-flowing asphaltic compound.

206. The connection from a header to a panel board is made from special fittings as shown in Fig. 163. Connection to the header is made with an adapter (Fig. 164, II) to which is connected the vertical elbow (Fig. 164, I). Straight sections of duct 1 ft. long (Fig. 164, IV) coupled together with couplings (Fig. 164, V) form the vertical run up the wall. The final section to the panel board is cut to length with a hack saw. The box connector (Fig. 164, III) holds the duct to the panel board. It requires an opening $1\frac{7}{8}$ by $5\frac{3}{4}$ in. in the bottom of the panel-board box.

207. Method of Installing Floor Outlets.—A hole of $1\frac{5}{8}$ in. diameter is cut in the center of a cell with a saw-type drill (Fig. 165, I). A forming

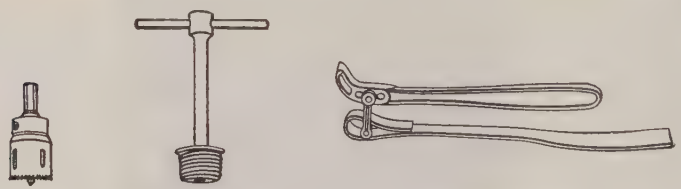


FIG. 165.—Tools for installing outlets in cellular-metal-floor raceways. (*H. H. Robertson Co.*)

tool (Fig. 165, II) is turned into the hole to prepare the hole for reception of the outlet tap. For floors with a concrete fill of 2 to $3\frac{1}{4}$ in. a standard adjustable tap (Fig. 166, I) is then screwed into the hole. For fills of 1 to 2 in. a special tap is available. For fills of less than 1 in. a shallow

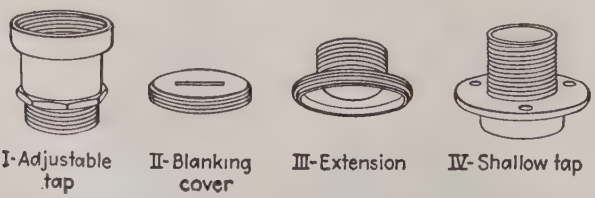


FIG. 166.—Fittings for cellular-metal-floor raceways. (*H. H. Robertson Co.*)

tap (Fig. 166, IV) is set in the hole and held in place with three No. 12 self-tapping screws. Holes for the screws must be drilled in the cell with a No. 9 drill. The top of the standard tap may be adjusted in height to the floor level, and a blanking cover (Fig. 166, II) installed until after

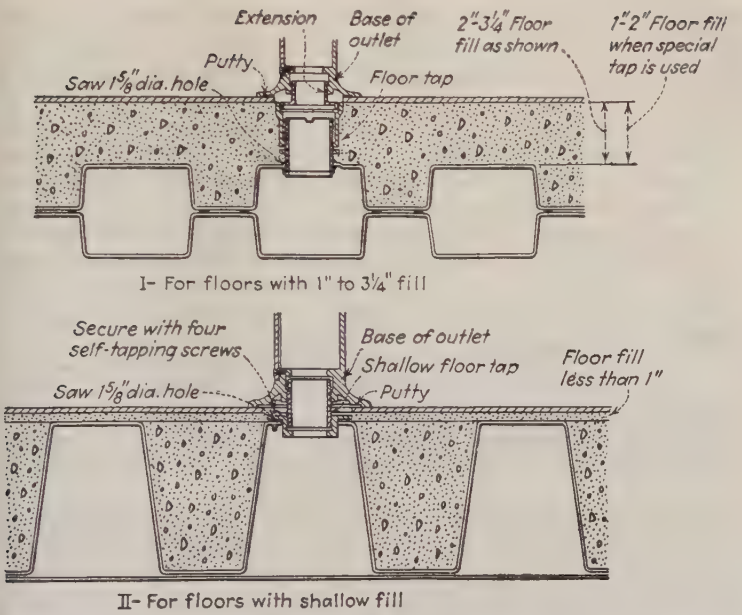
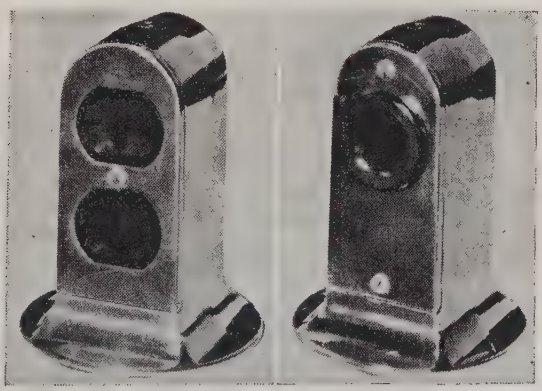


FIG. 167.—Assembly of floor outlets with cellular-metal-floor raceways. (*H. H. Robertson Co.*)



I. Duplex convenience outlet. II. Telephone outlet.

FIG. 168.—Outlets for use with cellular-metal-floor raceways. (*H. H. Robertson Co.*)

the floor is poured. In installing a floor outlet, the blanking cover is removed, and an extension (Fig. 166, III) is screwed into the tap. The floor outlet is then screwed onto the extension, using a warnock wrench (Fig. 165, III) or other type of fabric wrench to avoid marring the fitting. With the shallow tap (Fig. 166, IV) the fitting screws onto the tap directly without the use of the extension. The complete outlet assembly is shown in Fig. 167. A duplex convenience outlet and an outlet for bringing out a telephone cord are shown in Fig. 168.

208. Cell markers should be located on the center of each cell near the opposite side of the room from the header for future location of cells,

FIG. 169.—Markers for cellular-metal-floor raceways. (*H. H. Robertson Co.*)

when outlets are not installed initially. The access units in the header will identify the cell locations at the header. A straight line between the center of an access unit and a cell marker will then identify the cell so that an outlet may be located accurately at any time in the future. Several types of cell markers are shown in Fig. 169. The double-slot screw (Fig. 169, I) may be used to identify power-wire cells, and the single-slot one (Fig. 169, II) to identify telephone-wire cells. In installing these markers (Fig. 170) a hole is drilled and tapped in the top of the cell for a 12-24 screw before the floor fill is laid. The brass marker with a headless screw is then fastened in place and adjusted in height to the level of the finished floor. The marker should then be grouted in place. After the floor has been poured and the finished floor covering laid, the headless screw is replaced with one of the grommeted brass screws (Fig. 169, I or II).

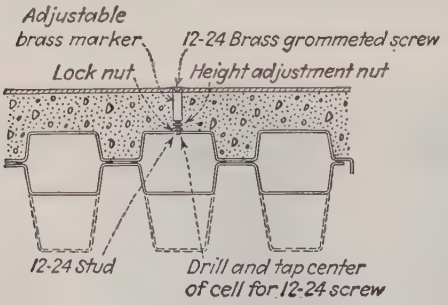


FIG. 170.—Detail showing cell marker. (*H. H. Robertson Co.*)

209. Underside headers must be used with Types III, V, and VI floors of Fig. 158, because there is not sufficient room for the other headers in the shallow floor fill. The underside header may also be used with the

Type IV floor when it is desired to add a header after the building is finished. The header (Fig. 171) is 5 in. wide by 2½ in. deep and should be mounted in the corner formed by the ceiling and wall so as to be as inconspicuous as possible (Fig. 172). It is held in place with No. 12 self-tapping screws which pass through holes drilled in the bottom of the raceways. Connection to a panel board is made with a special ell (Fig. 173, II) as shown in Fig. 174. Connection between the cells and the header is made by drilling a 2-in. hole in the cell to line up with the pilot opening in the header. A grommet (Fig. 173, I) with the lock nut removed is then inserted in the hole diagonally, as shown in Fig. 175. After the grommet has been adjusted to its proper position the lock nut is screwed on and holds the grommet firmly in place. At least two markers, as explained in Sec. **208,** should be located on top of the floor for each cell which does not have outlets installed initially.

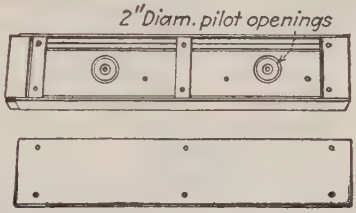


FIG. 171.—Underside header with cover removed. (*H. H. Robertson Co.*)

210. Ceiling lighting fixtures may be hung and wired from cellular-metal-floor raceways as shown in Fig. 176. At I is shown a fixture-stud

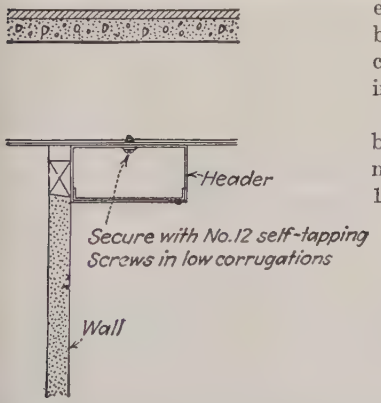


FIG. 172.—Section showing location and mounting of underside header. (*H. H. Robertson Co.*)

FIG. 173.—Fittings for underside header. (*H. H. Robertson Co.*)

mounting using the stud illustrated in Fig. 177, I. The fixture stud is inserted through a 2-in. hole cut in the cell similar to the grommet assembly of Fig. 175. A mounting for fixtures which fasten on the cover of a 4-in. box is shown in Fig. 176, II. The box (Fig. 177, II) is held in place with a grommet. The knockouts in the box may be used for surface conduit wiring if desired. A conduit-hung fixture is supported from the cell by means of a hanger as shown in Fig. 176, III. The hanger (Fig. 177, III) is held in place with a lock nut in the same way as the grommet.

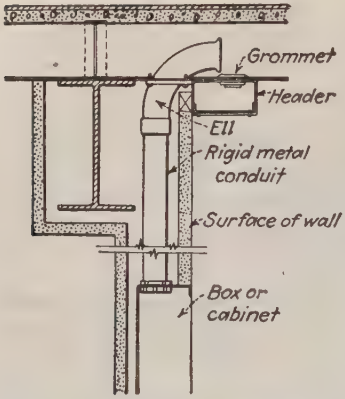


FIG. 174.—Section showing a method of connecting between underside header and panel. (*H. H. Robertson Co.*)

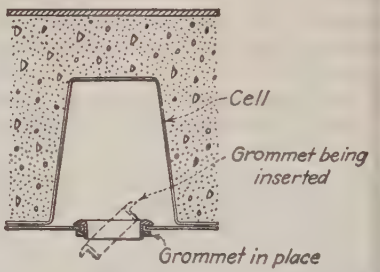


FIG. 175.—Showing method of inserting grommet into hole in cell. (*H. H. Robertson Co.*)

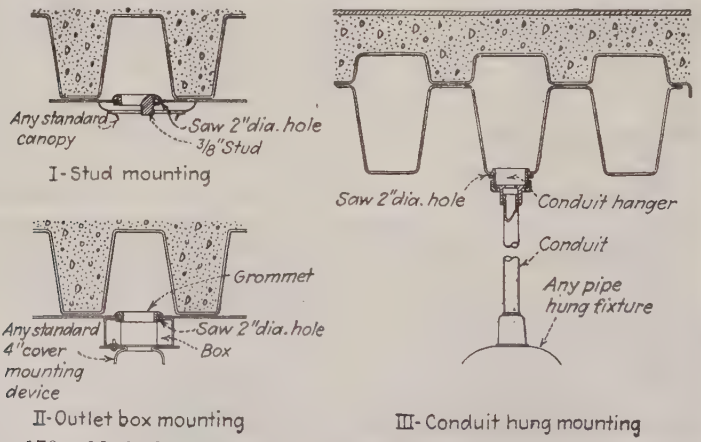


FIG. 176.—Methods of mounting ceiling fixtures from cellular-metal-floor raceways. (*H. H. Robertson Co.*)

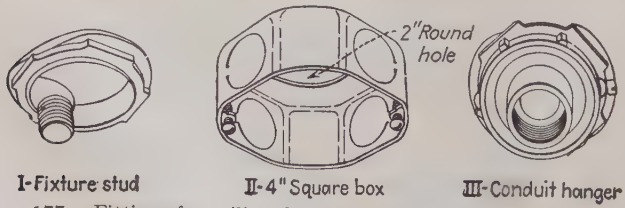


FIG. 177.—Fittings for ceiling fixtures. (*H. H. Robertson Co.*)

211. The cellular raceways are wired by fishing the wires from the access units to the outlets. No conductor larger than No. 1/0 may be installed except by special permission. The number of conductors in a cell is not limited as long as the total cross-sectional area of the conductors does not exceed 40 per cent of the internal area of the cell. All splices and taps must be made in the header or at junction boxes. The internal areas of the raceways shown in Fig. 158 are as follows:

Floor type	I	II	III	IV	V	VI	Connecting header	Underside header
Internal area, sq. in.	20	11	14.6	5.6	14.6	5.6	6	12.5

212. Cellular-metal-floor raceways are used principally for office buildings where the needs of the tenants for wiring outlets are not known very definitely in advance and where a high quality of adequacy and convenience of outlets and interior appearance is desired, having no exposed wiring. The position of the raceways may be varied in 6-in. increments, and a very flexible system of outlets for telephones, business machines, and desk lamps provided, with all outlets located under the desks out of sight. The cost may be lower than would be incurred if a standard floor with a large number of underfloor raceways were installed. The wiring for ceiling lighting outlets is also simplified where the type of floor is that in which the underside of the raceways serves as the ceiling.

WIRING WITH BARE CONDUCTORS

213. Bare conductors may be installed as feeders in a chase or shaft of noncombustible material in buildings of fire-resistive construction for voltages up to 600 volts. Since the design of buildings in which these conductors might be located varies widely, special permission for their use must be obtained from the authority enforcing the National Electrical Code. The location must not be hazardous or damp or contain corrosive vapors, except that bare conductors may be located in a storage-battery room, provided they are not taped. The size of conductors is determined by allowing a maximum current of 1,000 amp. per sq. in. of cross-sectional area of conductor if the enclosure is not ventilated, and 1,200 amp. per sq. in. if it is ventilated. The conductors must be supported on insulators and separated at least as great a distance as given in Table 214. The chase or shaftway must be so enclosed that the conductors are accessible only to qualified persons.

214. Minimum Spacing for Bare-conductor Feeders

Voltage	Opposite polarity when mounted on the same surface, spacing, in.	Opposite polarity when held free in air, spacing, in.	Live parts to ground, spacing, in.
Not over 125	¾	½	½
Not over 250	1¼	¾	½
Not over 600	2	1	1

WIRING WITH MULTIOUTLET ASSEMBLIES

215. Multioutlet assemblies consist of a metal raceway with single convenience outlets built in every few inches. In one type made by the

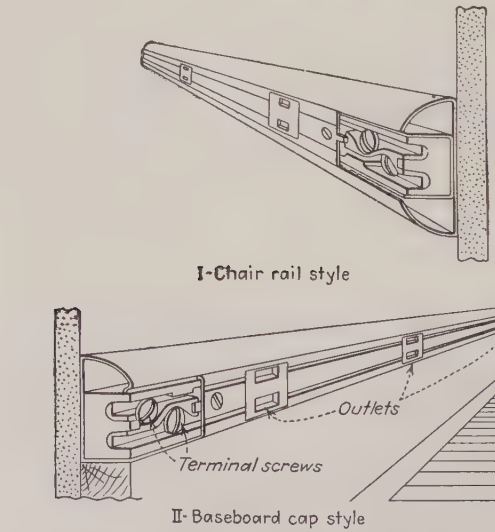


FIG. 178.—Plug-in strip. (*National Electric Products Corp.*)

Wiremold Co. the outlets may be spaced as desired along the raceway and connected by wires laid in the raceway. In another type (Fig. 178)

the outlets are built in at fixed intervals and connected by copper strips which terminate in terminal screws at each end of each length of raceway. This type is made in three styles according to the position in which it is to be used: (1) the chair-rail style for flat-surface mounting, (2) the baseboard-cap style for mounting on the top of baseboards or in corners of mantels and cabinets, and (3) the baseboard-insert style for recessing in the baseboard or in a plastered wall. Blank sections through which rubber-covered wires may be run to join plug-in sections are available for use behind radiators or for other inaccessible places where the expensive plug-in strip is not needed. Multioutlet assemblies are used to provide adequate plug receptacles for the utmost convenience in the use of appliances, principally in dwelling-type use.

216. Various ways of mounting the chair-rail style on plastered walls are shown in Fig. 179. Toggle bolts are used except where a wood strip

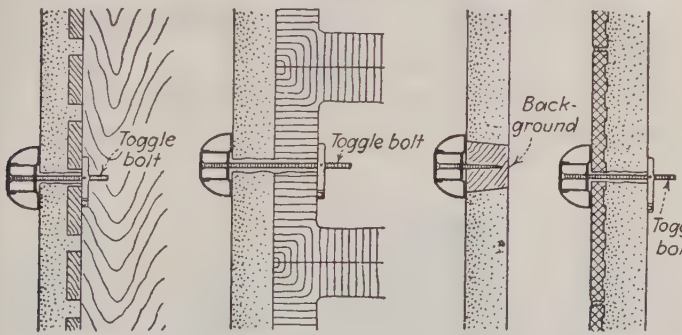


FIG. 179.—Methods of mounting chair-rail style of plug-in strip. (*National Electric Products Corp.*)

s available, as in III, when wood screws can be used. The chair-rail style is intended for mounting on flat surfaces at a considerable height above the baseboard. The curved surfaces on the top and bottom give the installation a neat appearance.

217. The baseboard-cap type has a flat surface on one edge and is curved on the other edge. It is used as illustrated in Fig. 180, where there is a corner against which the flat edge can be placed. The curved edge gives a finished appearance to the corner. In this type of mounting there is usually a wood background so that wood screws can be used for fastening.

218. The baseboard type is set into the wall so that the surface of the strip is flush with the wall surface. In wiring finished buildings with this

type, the molding on top of the baseboard is removed, the plug-in strip is placed on top of the baseboard, and the molding is placed against the plug-in strip (Fig. 181, III). For new installations a channel can be left in tile, glass, or marble surfaces as shown in Fig. 181, I and II, or the plaster may be channeled as shown in Fig. 181, IV.

219. Plug-in strip is made in various lengths from 6 in. to 9 ft. The lengths are joined together as shown in Fig. 182. Copper links connect

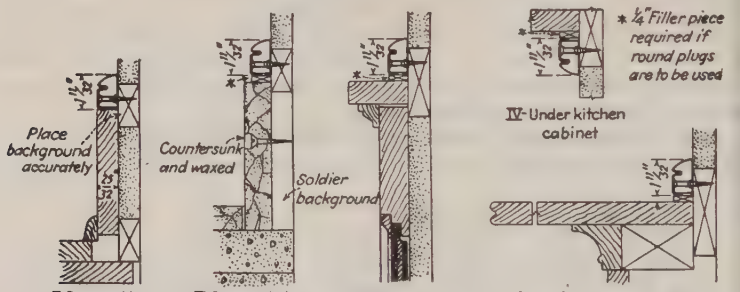


FIG. 180.—Methods of mounting baseboard-cap style of plug-in. strip. (*National Electric Products Corp.*)

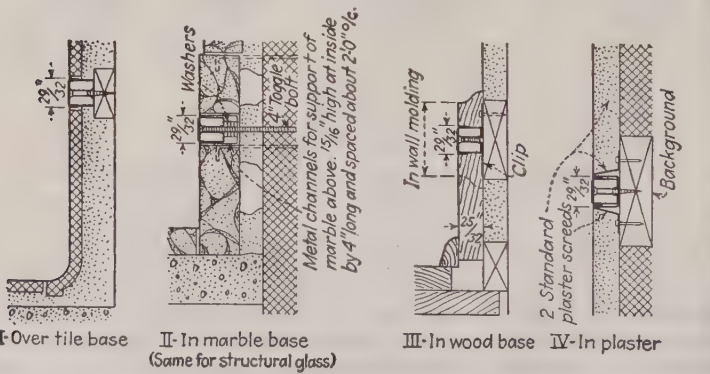
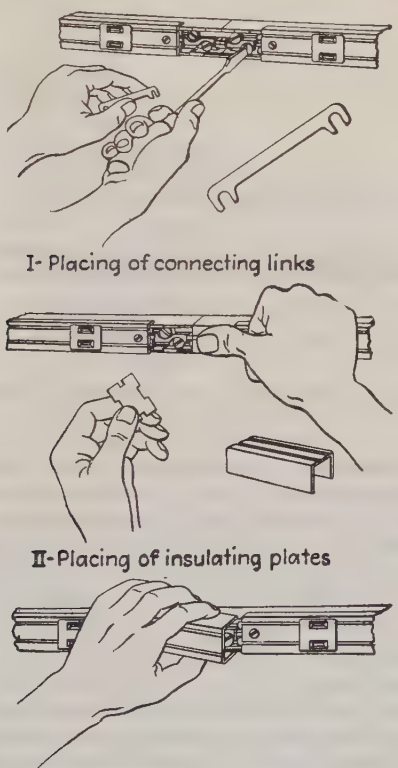


FIG. 181.—Methods of mounting baseboard-insert style of plug-in strip. (*National Electric Products Corp.*)

the terminal screws on two adjoining lengths of plug-in strip (Fig. 182, I). Then insulating plates are placed over the terminals (Fig. 182, II), and the joint is covered with a coupling of the same exterior finish as the plug-in strip.

220. The method of bringing in the supply circuit is shown in Fig. 183. Junction boxes are available for either armored cable or rigid conduit.

The junction box has a hub in the back with a setscrew for clamping armored cable or threaded for $^1_2$-in. conduit connection (Fig. 183, I). The circuit wires are stripped as shown, and two short lengths of rubber-covered wire are spliced to them so that the circuit will feed both ways from the junction box. The junction box is then placed against the wall,



IG. 182.—Method of coupling plug-in strips together. (*National Electric Products Corp.*)

nd the wires are connected to the terminal screws in the adjoining plug-n strips (Fig. 183, II). The middle section of the junction box is closed y means of a cover, held in place by two screws. Over each pair of erminals an insulating plate is placed and then covered with a coupling late.

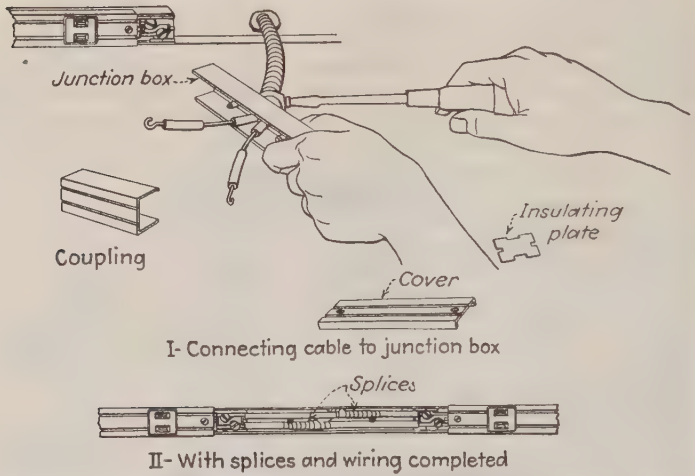


FIG. 183.—Method of bringing supply circuit into plug-in strip. (*National Electric Products Corp.*)

GENERAL REQUIREMENTS FOR WIRING INSTALLATIONS

CONDUCTOR REQUIREMENTS

221. Size of Conductors.—No wire smaller than No. 14 is allowed for general interior wiring work. Wires of No. 18 or No. 16 may be used for fixture wiring, flexible cords, and for some other special applications as given in Sec. **38** of Div. 3. Although No. 14 wire is allowed for branch circuits, it is good practice not to use smaller than No. 12. Number 12 wire costs only about 20 per cent more than No. 14, can usually be placed in the same size conduit or raceway, will have greater mechanical strength, and will reduce the voltage drop and the I^2R heating loss in the wires by approximately 40 per cent. Solid conductors of larger size than No. 8 are not allowed to be used in conduit or raceways. For ease in handling it is good practice to use stranded conductors in the larger sizes for open wiring also. The size of wire required, according to the amount of current to be carried by the circuit, is discussed in Sec. **37A** of Div. 3, and the ampere current-carrying capacities are given in Tables 15 to 18*B* of Div. 11.

222. All ungrounded conductors must be protected by fuses or circuit breakers rated in accordance with the allowable carrying capacity of the conductors as given in Sec. **223** and located at the point where the conductor receives its supply, with the following exceptions:

1. For building-service conductors the overcurrent protection is located at the same point as the other service-entrance equipment, which may be at the load end of the service-entrance conductors.

2. The overcurrent protection may be omitted, provided the overcurrent unit farther back on the circuit is rated not greater than the carrying capacity of the smaller conductor.

3. If a tap conductor is not over 5 ft. long, does not extend beyond the switchboard, panel board, or control devices which it supplies, is enclosed, and has a current-carrying capacity not less than the sum of the capacities of the circuits which it supplies, it need not be separately protected.

4. If the conductor is not over 25 ft. long, is protected from mechanical injury, and has a current-carrying capacity not less than one-third that of the conductor from which it is supplied, the overcurrent device may be located at the load end of the conductor.

5. For individual motor branch circuits, refer to Sec. **442,** Div. 7.

6. For feeders or main conductors supplying more than one motor, refer to Sec. **447,** Div. 7.

7. For fixture wires and flexible cords, refer to Sec. **225.**

223. Rating of the Overcurrent Protective Devices.—The rating of the overcurrent protective device must be as given below except for the exceptions referred to in Sec. **222** (5), (6), and (7). Fuses or circuit breakers shall have ratings not greater than the allowable carrying capacity of the conductor which they protect, except as follows:

1. Adjustable circuit breakers of instantaneous-trip type, thermal-trip type, or time-delay magnetic-trip type shall be set to trip at not more than 150 per cent of the allowable carrying capacity of the protected conductor. Circuit breakers from 0 to 30 amp. should be of the time-delay type.

2. Where one of the above rules does not give a standard size of fuse or circuit breaker the next higher standard size may be used, provided it does not exceed the allowable current-carrying capacity of the conductor by more than 50 per cent.

The allowable carrying capacity of wires is given in Tables 18 and 18*A* of Div. 11, and the common sizes of fuses and circuit breakers in Table 33 of Div. 11.

224. Grounded conductors must not be fused and must not have a circuit breaker in them unless the circuit breaker opens all the wires of the circuit at the same time. The size of the grounded conductor may be changed whenever the sizes of the other conductors are changed, provided the other conductors are protected as outlined in Secs. **222** and **223** (see Div. 8, Sec. **168,** for an explanation of the reason for grounding one conductor of a wiring system). In locations where the possibility of reversal of connections warrants, the authority enforcing the Code may require overcurrent devices in both conductors of two-wire branch circuits.

225. Flexible cords are used for wiring fixtures, for connection of portable appliances, or for the connection of approved stationary devices to facilitate their interchange or to prevent transmission of noise or vibration. (See Div. 2 for a complete listing of flexible cords.) Flexible

cords must be not smaller than No. 18, and if the load connected to them is not greater than their carrying capacity they are considered as sufficiently protected by the branch-circuit overcurrent device of the branch circuit from which they are tapped. For the carrying capacity of fixture wire see Table 18*B*, Div. 11. Cords must be connected to devices so that tension in the cord will not be taken by the terminal screws. This may be accomplished by knotting the cord inside the device (Fig. 184), by winding it with tape, or by using a clamp fitting. Where flexible cords pass through the cover of an outlet box the hole must have a smooth well-rounded surface; where they enter lamp holders they must be protected by insulating bushings. Flexible cords must be used in continuous lengths without splice or tap. For voltages between 300 and 600, Type S, SO, SU, SUU, or ST cord or cords with at least $\frac{3}{64}$ in. of rubber or thermoplastic insulation on each conductor must be used.

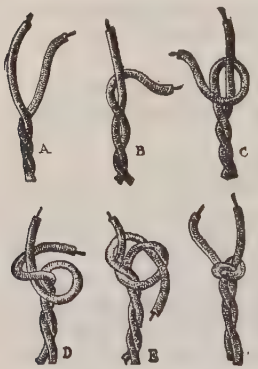


FIG. 184.—Method of tying supporting knot in flexible cord (see Sec. **225** for description).

In the wiring of fixtures, use conductors having insulation suitable for the current, voltage, and temperature to which they will be subjected. The splice between the fixture conductors and the circuit conductors must be easily accessible for inspection without requiring disconnection of the wiring. This is accomplished by making the canopy so that it will slide down the fixture stem (Fig. 186).

226. Splicing of Conductors.—Conductors in conduit or raceway systems must be continuous from outlet to outlet and must not be spliced or tapped within the raceway or conduit itself, except in wireways or auxiliary gutters. Instructions for the proper splicing of conductors are given in Div. 2.

227. Conductors may be placed in multiple in sizes 1/0 to 500,000 cir. mils provided they are the same length and size and have the same type of insulation. Not more than three No. 1/0, four No. 2/0, or five Nos. 3/0 to 500,000 cir. mils may be run in multiple. If the parallel circuits should be carried in different conduits or raceways, at least one wire of each phase should be carried in each conduit or raceway.

228. Conductors of a-c systems must be run with all phases of the circuit located in the same metal enclosure, such as conduit and raceway, in order that the m.m.f. in the metal enclosure, produced by the current in one of the conductors, will be almost completely neutralized by the m.m.f. produced by the current in the other conductors of the circuit. Thus heating of the enclosures by induced currents will be kept at a minimum, and inductance and inductive reactance also reduced. It is

recommended that this procedure be followed with d-c systems to facilitate a change to alternating current at some later date.

229. At outlets and switch locations at least 6 in. of free conductor must be left for the making of joints and connection of wiring devices.

230. When ungrounded conductors of No. 4 and larger enter a cabinet, junction, or pull box, they shall be protected by a smoothly rounded insulating bushing, unless they are separated from the raceway fitting by substantial insulating material securely fastened in place. If conduit bushings are constructed wholly of insulating material, a lock nut shall be provided both inside and outside the enclosure to which the conduit is attached. If the conductors enter the cabinet vertically a gutter must be provided with a width as specified in Sec. **86,** Div. 4.

231. Conductors of different systems must be kept in enclosures separate from each other. For carrying out this requirement the National Electrical Code recognizes three different conductor systems, as follows, without regard to whether the circuits are a-c or d-c:

1. Conductors of **more** than 600 volts.

2. Conductors of **less** than 600 volts. All conductors in the enclosure must be insulated for the maximum voltage of **any** conductor in the enclosure.

3. Conductors of signal or radio systems with exceptions for elevators, sound-recording systems, and where the power wires supply the signaling system.

232. When conductors or cables are run through bored holes in studs and joists, the holes should be bored at the approximate centers of wood members, or at least 2 in. from the nearest edge. Where there is no objection because of weakening the building structure, armored or nonmetallic-sheathed cable may be laid in notches in the studding or joists if the cable at those points is protected against the driving of nails into it by having the notch covered with a steel plate at least $\frac{1}{16}$ in. thick before the building finish is applied.

233. Conductors in vertical raceways (**any metallic enclosure for conductors**) must be supported at intervals not greater than those given in Sec. **94** under Conduit Wiring.

233A. The approved types of insulation of conductors for different installations are given in Sec. **24.**

234. Insulation Resistance.—In order that a reasonable factor of safety against short circuits and grounds shall be provided, the National Electrical Code recommends that completed wiring systems should have an insulation resistance not less than that given in the following specifications:

For circuits of No. 14 or No. 12 wire..... 1,000,000 ohms

For circuits of No. 10 or larger conductor, a resistance, based upon the allowable current-carrying capacity of conductors as given in Tables 18 and 18*A* of Div. 11, as follows:

Amp.	Ohms
25– 50	250,000
51–100	100,000
101–200	50,000
201–400	25,000
401–800	12,000
Over 800	5,000

The test for the insulation resistance should be made with a megger (see Div. 1) with all switchboards, panel boards, switches, and overcurrent devices in place. If lamp holders, receptacles, fixtures, or appliances are also connected, the resistances for branch circuits may be one-half of the above values. Where climatic conditions expose the wiring to excessive humidity the values may have to be modified.

General Installation Requirements

235. Coating of Wiring Materials (National Electrical Code).—Metal raceways, cable armor, cabinets, and all metallic elbows, couplings, and fittings, unless made of corrosion-resistant material, shall be suitably protected against corrosion inside and outside (except threads at joints) by a coating of approved corrosion-resistant material such as zinc, cadmium, or enamel, except that ferrous raceways and fittings protected from corrosion solely by enamel may be used only indoors and in occupancies not subject to severe corrosive influences.

Meat-packing plants, tanneries, hide cellars, casing rooms, glue houses, fertilizer rooms, salt storage, some chemical works, metal refineries, pulp mills, sugar mills, round houses, some stables, and similar locations are judged to be occupancies where severe corrosive conditions are likely to be present.

236. Outlet boxes (see Div. 4) must be provided at each outlet, switch, or junction point for all wiring systems except open wiring. Wherever a change is made from open or concealed knob and tube wiring to one of the other types of wiring, a box or terminal fitting which has a separately bushed hole for each conductor must be used. In terminating conduit wiring at switchboards and control-apparatus locations an insulating bushing instead of a box may be used, and the conductors bunched, taped, and painted with insulating paint. If conductors are lead covered the bushing need not be an insulated one.

237. Number of Conductors in a Box (National Electrical Code).—Boxes shall be of sufficient size to provide free space for all conductors enclosed in the box.

1. The maximum number of conductors, not counting fixture wires, permitted in outlet and junction boxes shall be as in the following tables with the exceptions noted following the table:

Box dimensions, trade size, in.	Max. number of conductors			
	No. 14	No. 12	No. 10	No. 8
Deep Boxes				
1½ × 3¼ octagonal	5	5	4	0
1½ × 4 octagonal	8	7	6	5
1½ × 4 square	11	9	7	5
1½ × 4 1/16 square	16	12	10	8
2⅛ × 4 1/16 square	20	16	12	10
1¾ × 2¾ × 2	5	4	4	
1¾ × 2¾ × 2½	6	6	5	
1¾ × 2¾ × 3	7	7	6	
Shallow Boxes of Less Than 1½-in. Depth				
3¼	4	4	3	
4	6	6	4	
4 1/16	8	6	6	

The tables apply where no fittings or devices, such as fixture studs, hickeys, cable clamps, switches, or receptacles, are contained in the box. Where a fixture stud, cable clamp, or hickey is contained in the box, the number of conductors permitted shall be one less than shown in tables, with a further deduction of one for each flush device or combination of flush devices mounted on the same strap. A conductor running through the box is counted as one conductor, and each conductor terminating in a box is also counted as one conductor.

2. For combinations not shown in the preceding tables the following table shall apply:

Size of Conductor	Free Space within Box for Each Conductor, Cu. In.
No. 14	2.
No. 12	2.25
No. 10	2.5
No. 8	3.

3. The limitations in subparagraphs 1 and 2 of this section shall not apply to terminal housings supplied with motors, or to types of boxes or fittings without knockouts and having hubs or recessed parts for terminal bushings and lock nuts.

This section does not apply to conductors used for rewiring existing raceways.

238. Pull Boxes.—The National Electrical Code requires that the size of all pull boxes located in a run of raceway or conduit of 1¼-in. trade

size or larger containing conductors of No. 6 or larger shall conform to the following specifications:

1. For straight pulls the length must be not less than eight times the trade size of the raceway.

2. For angle pulls the distance between any raceway and the opposite wall must be not less than six times the trade size of the raceway. To this value must be added the trade size of any additional raceways entering the box. The distance between raceway entries enclosing the same conductor must be not less than six times the trade diameter of the larger raceway.

239. All conduits and raceways must be continuous from outlet to outlet and from fitting to fitting and must be securely fastened in place. Fittings must be mechanically secured to conduits, raceways, and boxes, and the entire metallic-enclosure system must form an electrically continuous conductor. If different portions of a conduit or raceway system are exposed to widely different temperatures, as in refrigerating or cold-storage plants, provision must be made to prevent circulation of air through the raceway from a warmer to a colder section.

240. Covers and Canopies.—The National Electrical Code requires that each outlet box shall be provided with a cover unless a fixture canopy is used.

1. If a fixture canopy is used, any combustible wall or ceiling finish exposed between the edge of the canopy and the outlet box shall be covered with noncombustible material.

2. Nonmetallic covers and plates shall be used with nonmetallic outlet boxes.

3. Covers of outlet boxes and outlet fittings having holes through which flexible-cord pendants pass shall be provided with bushings designed for the purpose or shall have smooth, well-rounded surfaces on which the cord may bear. So-called hard-rubber or composition bushings shall not be used. If conductors other than flexible cord pass through a metal cover, there shall be provided a separate hole for each conductor, said hole being equipped with a bushing of insulating material.

241. Position of Outlet Boxes in Wall (National Electrical Code).—In walls or ceilings of concrete, tile, or other noncombustible material, boxes, fittings, and cabinets shall be so installed that the front edge of the box or fitting will not set back of the finished surface more than ¼ in. In walls and ceilings constructed of wood or other combustible material, outlet boxes, fittings, and cabinets shall be flush with the finished surface or project therefrom.

In making an exposed extension from an existing outlet of concealed wiring, a box, extension ring, or blank cover shall be mounted over the original box and electrically and mechanically secured to it. The extension shall then be connected to this box in the manner prescribed for the method of wiring employed in making the extension.

Unused openings in boxes, fittings, and cabinets shall be effectively closed to afford protection substantially equivalent to that of the wall of the box, fitting, or cabinet. Metal plugs or plates shall not be used with nonmetallic boxes, fittings, or cabinets unless recessed at least ¼ in. from the outer surface.

242. Ceiling outlet boxes may be supported with wood screws projecting through the holes in the bottom of the box, in frame construction when a wood background is available. Where boxes must be supported between wooden beams, bar hangers as shown in Sec. **115**, Div. 4, are used. The hangers are fastened with nails or wood screws to the beams. The box is fastened to the hanger by means of the fixture stud or with

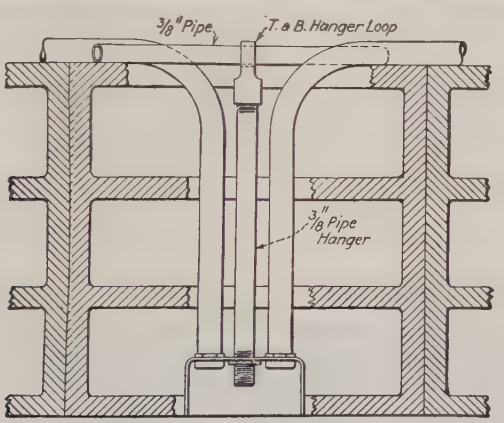


FIG. 185.—Support for outlet box in terra-cotta ceiling.

two bolts. With concealed conduit wiring in reinforced-concrete ceilings the conduits and the edges of the backing plate of the concrete boxes, bearing against the concrete, support the box. With terra-cotta ceilings a tee made of ⅜-in. pipe substantially bearing on the top of the terra-cotta should be used (Fig. 185). The pipe projects through the fixture-stud knockout in the back of the box and forms the fixture stud. For exposed wiring on concrete ceilings, screws and lead expansion sleeves should be used. For exposed wiring on steelwork the box should be bolted to the steel.

For exposed wiring on plastered ceilings the box may be fastened on the surface with toggle bolts.

Wall outlet boxes in frame construction are fastened to the studs with side hangers which form part of the box (see Sec. **116**, Div. 4). With concealed wiring in concrete or brick walls the masonry, being built tight around the box, supports it. The conduit prevents the box from coming loose from the wall. If a pocket has been cut in a brick wall to

receive an outlet box and the wall has been channeled for the conduit, the box should be fastened to the wall by means of two expansion sleeves. With concealed wiring in concrete construction, for the support of a fixture which is of too great weight to be safely hung on an ordinary ⅜-in. fixture stud, the outlet box should be supported by means of a pipe support similar to that of Fig. 185, embedded in the concrete. For exposed wiring on concrete and brick walls the box may be fastened with wood screws in lead expansion sleeves. For exposed conduit wiring, conduit boxes of less than 100 cu. in. in size need not be fastened if the conduit is secured in threaded hubs on the box.

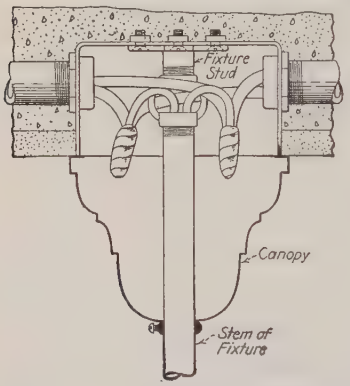


FIG. 186.—Method of supporting a fixture from a fixture stud.

243. Lighting fixtures are usually supported from the fixture stud in the outlet box (Fig. 186). A hickey is screwed onto the fixture stud, and the fixture stem is screwed into the hickey. The fixture wires are brought out of the fixture stem through the holes in the hickey and spliced to the circuit wires. The canopy is then slipped up against the ceiling and fastened to the fixture stem with a setscrew. In many cases it is preferable to use outlet boxes which have the fixture stud made integral with the back of the box. In case that type of box is not available, a separate fixture stud (Fig. 187) may be installed. The no-bolt type (Fig. 187, I) is used for supporting the box from a bar hanger. The body of the stud is on the back of the hanger with the threaded portion projecting through the hanger and through a hole in the center of the box. The nut is screwed on the stud inside the box and holds the box to the hanger. The bolted type (Fig. 187, II) is either bolted to the back of the box or, when the box is supported from a wooden member, is held in place with wood screws. The National Electrical Code requires that a fixture which weighs more than 6 lb. or exceeds 16 in. in any dimension must not be supported by the screw shell of the lamp holder. Small lighting fixtures consisting of a lamp holder and a small shade may be supported from a pendent cord. In this case a box cover with a round hole in the center is used. A knot is tied in the cord inside the box (Fig.

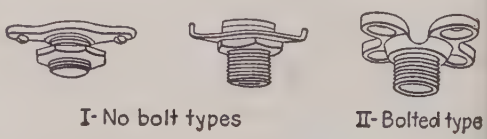


FIG. 187.—Fixture studs.

184) so that the knot will bear against the cover and support the weight of the fixture. With exposed conduit wiring, elbow or tee conduit fittings are frequently used. The fixture is supported with a short length of conduit which threads into the fixture and into the hub which projects down from the fitting. Sometimes the upper part of the fixture is designed to be fastened as the cover on a 3¼- or 4-in. outlet box. A fixture which weighs more than 50 lb. must be supported independently of the outlet box.

244. Working Space about Electrical Equipment (National Electrical Code).—Suitable working space shall be provided and maintained about all electrical equipment.

a. Horizontal Dimensions.—Except as elsewhere required or permitted in this Code, the horizontal dimensions of the working space in front of live parts, operating at not more than 600 volts, which must be handled while alive, shall not be less than:

1. For parts of more than 150 volts to ground on one side of the working space and no bare live or grounded parts on the other side of the working space, 2½ ft.
2. For parts of more than 150 volts to ground on one side of the working space and bare live or grounded parts on the other side of the working space, 4 ft.
3. For parts of 150 volts or less to ground on one side of the working space and no bare live or grounded parts on the other side of the working space, 1½ ft.
4. For parts of 150 volts or less to ground on one side of the working space and bare live or grounded parts on the other side of the working space, 2½ ft.
5. For parts of 600 volts and over, see Table 31, Div. 11.

b. Clear Spaces.—Working spaces adjacent to exposed live parts shall not be used as passageways.

c. Elevation of Equipment.—The elevation of the equipment at least 8 ft. above ordinarily accessible working platforms usually affords protection at least equivalent to that provided by the horizontal clearances of paragraph *a* and may be used in lieu thereof.

d. Guarding of Live Parts.—In general, exposed live parts of electrical equipment operating at 50 volts or more shall be guarded against accidental contact, by enclosure or by locating the equipment as follows:

1. In a room or enclosure which is accessible only to qualified persons.
2. On a suitable balcony, gallery, or platform, so elevated and arranged as to exclude unqualified persons.
3. Elevated 8 ft. or more above the floor.
4. So that it will be protected by a guard rail if the equipment operates at 600 volts or less.

e. Spacing from Lightning Rods.—Metal frames and cases of electric equipment shall, wherever practicable, be kept at least 6 ft. away from

lightning-rod conductors. Where it is not practicable to secure 6 ft. separation, they shall be bonded together.

245. Auxiliary Gutters (National Electrical Code).—Auxiliary gutters, used to supplement wiring spaces at meter centers, distribution centers, switchboards, and similar points of interior wiring systems, may enclose conductors or bus bars but shall not be used to enclose switches, overcurrent devices, or other appliances or apparatus.

a. Extension beyond Equipment.—An auxiliary gutter shall not extend a greater distance than 30 ft. beyond the equipment which it supplements, except in elevator work. Any further extension shall comply with the rules for wireways or bus ways.

b. Supports.—Gutters shall be supported throughout their entire length at intervals not exceeding 5 ft.

c. Covers.—Covers shall be securely fastened to the gutter.

d. Number of Conductors.—Auxiliary gutters shall not contain more than 30 conductors at any cross section unless the conductors are for signaling circuits or are control conductors between a motor and its starter and are used only for starting duty. The sum of the cross-sectional areas of all contained conductors at any cross section of an auxiliary gutter shall not exceed 20 per cent of the interior cross-sectional area of the gutter.

e. Carrying Capacity of Copper Bars.—The current carried continuously in bare conductors in auxiliary gutters shall not exceed 1,000 amp. per sq. in. of cross section of the conductor.

f. Clearance of Bare Live Parts.—Bare conductors shall be securely and rigidly supported so that the minimum clearance between bare current-carrying metal parts of opposite polarities mounted on the same surface shall be not less than 2 in. or less than 1 in. for parts that are held free in the air. A spacing not less than 1 in. shall be secured between bare current-carrying metal parts and any metal surface. Adequate provision shall be made for expansion and contraction of copper bars.

g. Splices and Taps.—Splices and taps shall conform to the following:

1. Splices or taps, made and insulated by approved methods, may be located within gutters if they are accessible by means of removable covers or doors. The conductors, including splices and taps, shall not fill the gutter to more than 75 per cent of its area.

2. Taps from bare conductors shall leave the gutter opposite their terminal connections, and conductors shall not be brought in contact with uninsulated current-carrying parts of opposite polarity.

3. All taps shall be suitably identified at the gutter as to the circuit or equipment which they supply.

4. Tap connections from conductors in auxiliary gutters shall be provided with overcurrent protection in conformity with the provisions of Sec. **223.**

h. Construction.—Auxiliary gutters shall be constructed in accordance with the following:

1. Gutters shall be so constructed and installed that adequate electrical and mechanical continuity of the complete raceway system will be secured.

2. Gutters shall be of substantial construction and shall provide a complete enclosure for the contained conductors. All surfaces, both interior and exterior, shall be suitably protected from corrosion. Corner joints shall be made tight, and, where the assembly is held together by rivets or bolts, these shall be spaced not more than 12 in. apart.

3. Suitable bushings, shields, or fittings having smooth rounded edges shall be provided where conductors pass between gutters, through partitions, around bends, between gutters and cabinets or junction boxes, and at other locations where necessary to prevent abrasion of the insulation of the conductors.

4. Gutters shall be constructed of sheet metal of thicknesses not less than in the following table:

Max. width of the widest surface of gutters	Size	Thickness, U. S. Standard sheet-steel gage, in.
Up to and including 6 in.	No. 16	0.0598
Over 6 in. and not over 18 in.	No. 14	0.0747
Over 18 in. and not over 30 in.	No. 12	0.1046
Over 30 inches	No. 10	0.1345

Grounding

246. There are two types of grounds in interior wiring systems:

1. System grounds.

2. Equipment and conductor-enclosure grounds.

A system ground refers to the condition of having one wire of a circuit connected to ground. The reason for doing this is explained in Sec. **170,** Div. 8.

An equipment or conductor-enclosure ground refers to connecting the non-current-carrying metal parts of the wiring system or equipment to ground. This is done so that the metal parts with which a person might come in contact are always at or near ground potential. With this condition there is no danger that a person touching the equipment or conductor enclosure will receive a shock. Also metal conduit, raceways, and boxes may be in contact with metal parts of the building at several points. If an accidental contact occurs between an ungrounded conductor and its metal enclosure, a current may flow to ground through a stray path made up of sections of metal lath, metal partitions, piping,

or other similar conductors. If the equipment is grounded the resistance of the path through the grounding conductor will usually be much less than the resistance through the stray path, and not much current will flow through the stray path. Sufficient current will usually flow through the grounded path to blow the circuit fuse or trip the circuit breaker and thus open the circuit until repairs can be made. On the other hand, if the equipment is not grounded, sufficient current may flow through the stray path to heat up some section to a sufficient temperature to ignite wood or other inflammable material with which it is in contact. The current may not be sufficient to operate the fuse or circuit breaker, especially if the contact occurs on large-sized feeders.

247. The following items of equipment and conductor enclosures must be grounded:

1. All metallic conductor enclosures, except in runs of less than 25 ft which are free from contact with grounded metal and which, if within reach from grounded metal, are guarded against contact by persons, including:
   - *a.* Rigid or flexible metal conduit.
   - *b.* Metal raceways of all types.
   - *c.* Armor of any cable with a metallic armor.
   - *d.* Wireways and bus ways.
   - *e.* Auxiliary gutters.
2. Metal cabinets.
3. Metal outlet or switch boxes.
4. Metal junction or pull boxes.
5. Metal fixtures connected to a wiring system enclosed in a metallic enclosure.
6. Metal fixtures connected to a wiring system, if not over 150 volts which is not enclosed in a metallic enclosure, when the fixture is mounted on metal or metal-lath ceilings and walls. If the fixture is insulated from its support and the metal lath by use of insulating joints or fixture supports and canopy insulators, the fixture need not be grounded.
7. All metal fixtures connected to a system of over 150 volts to ground.
8. Metallic structures of nonelectrical equipment as follows:
   - *a.* Frames and tracks of electrically operated cranes.
   - *b.* The metal frame of a nonelectrically driven elevator car to which electric conductors are attached.
   - *c.* Hand-operated metal shifting ropes or cables of electric elevators.
   - *d.* Metal enclosures such as partitions, grillwork, etc., around equipment carrying voltages in excess of 750 volts between conductors unless in substations or vaults under the sole control of the supply company.
9. Fixed motor, generator, transformer, and capacitor frames and other non-current-carrying parts of any fixed electrical equipment

[electric ranges are considered as fixed equipment even though connected by a plug and flexible cord) under the following conditions:

a. If equipment is supplied by means of metal-clad wiring.

b. If equipment is located in a wet location and is not isolated.

c. If equipment is in a hazardous location (see Sec. **293**).

d. If equipment is in electrical contact with metal or metal lath.

e. If equipment is located within reach of a person who is standing on the ground or who can make contact with any grounded surface or object.

f. If equipment operates with any terminal at more than 150 volts to ground, except as follows:

(1) Enclosures for switches or circuit breakers where accessible to qualified persons only.

(2) Metal frames of electrically heated devices, exempted by special permission, in which case the frames shall be permanently and effectively insulated from ground.

(3) Transformers mounted on wooden poles at a height of more than 8 ft. from the ground.

10. Controller cases for motors, except those attached to ungrounded portable equipment and except lined covers of snap switches.

11. Electric equipment of elevators and cranes.

12. Electric equipment in garages, theaters, and motion-picture studios, except pendent lamps on circuits of not more than 150 volts to ground.

13. Motion-picture projection equipment.

14. Electric signs and associated equipment, unless these are inaccessible to unauthorized persons and are also insulated from ground and from other conductive objects.

15. Generator and motor frames in an electrically operated organ, unless the generator is effectively insulated both from ground and from the motor driving it.

16. Switchboard frames, except frames of d-c, single-polarity switchboards which are effectively insulated.

17. X-ray tubes used in therapy.

18. Non-current-carrying metal parts of portable equipment under following conditions:

a. In hazardous location.

b. If operated more than 150 volts to ground, except:

(1) Motors, if guarded.

(2) Metal frames of electrically heated appliances, and X-ray tubes used in therapy, exempted by special permission.

c. In other than residential occupancies, exposed metal parts of portable appliances used in damp or wet locations or by persons standing on the ground or on metal floors or working inside metal tanks or boilers shall be grounded, except where supplied through

an insulating transformer with ungrounded secondary of not over 50 volts.

This paragraph shall not be construed to prohibit the use of an insulating transformer with a secondary voltage greater than 50 volts, if the exposed metal parts of the appliance connected to such a transformer are grounded, and provided other conditions of this article are fulfilled.

It is recommended that the frames of all portable motors which operate at more than 50 volts and less than 150 volts to ground be grounded, where this can be readily accomplished.

19. All instrument-transformer cases except of current transformers, the primaries of which are not over 150 volts to ground and which are used exclusively to supply current to meters.

20. Cases of instruments, meters, and relays operating at voltages of 750 volts or less under the following conditions:

a. Not on Switchboards.—Instruments, meters, and relays not located on switchboards, which operate with windings or working parts at 300 volts or more to ground, and accessible to other than qualified persons, shall have the cases and other exposed metal parts grounded.

b. On Dead-front Switchboards.—Instruments, meters, and relays (whether operated from current and potential transformers or connected directly in the circuit) on switchboards having no live parts on the front of the panels shall have the cases grounded.

c. On Live-front Switchboards.—Instruments, meters, and relays (whether operated from current and potential transformers or connected directly in the circuit) on switchboards having live parts on the front of panels shall not have their cases grounded. Rubber mats or other suitable floor insulation shall be provided for the operator if the voltage to ground exceeds 150.

21. *Cases of Instruments, Meters, and Relays—Operating Voltage over* 750.—Where instruments, meters, and relays have current-carrying parts over 750 volts to ground, they shall be isolated by elevation or protected by suitable barriers, grounded metal, or insulating covers or guards. Their cases shall not be grounded, except as follows:

In electrostatic ground detectors the internal ground segments of the instrument are connected to the instrument case and grounded; the ground detector shall be isolated by elevation.

Instrument Grounding Conductor.—The grounding conductor for secondary circuits of instrument transformers and for instrument cases shall not be smaller than No. 12, if of copper, or, if of other metal, shall have equal conductance.

248. The types of wiring systems required to have a system ground are as follows:

1. Two-wire, d-c systems of not more than 300 volts, unless the system supplies industrial equipment in limited areas and is equipped with a ground detector as described in Div. 1.

2. Three-wire, d-c systems.

3. Alternating-current systems, provided the grounded conductor is so arranged that the maximum voltage to ground is between 50 and 150 volts. Grounding is also recommended where the voltage to ground will be between 150 and 300 volts, and is allowable in some cases on higher voltages. Any uninsulated service conductor must be grounded.

4. Alternating-current systems of less than 50 volts if supplied by transformers from systems of more than 150 volts to ground or from ungrounded systems or if run overhead outside buildings.

5. Secondary circuits of current and potential instrument transformers, when primary winding is connected to a circuit of 300 volts or more to ground, and in all cases when mounted on switchboard.

248A. Circuits Which Must Not Be Grounded.—1. Circuits operating at more than 300 volts to ground except with special permission.

2. Circuits for electric cranes operating over combustible fibers in Class III hazardous locations (refer to Sec. **293** for description of hazardous locations).

249. The Location of the System Ground (Fig. 188).—1. For d-c systems the ground must be at the supply station and nowhere else.

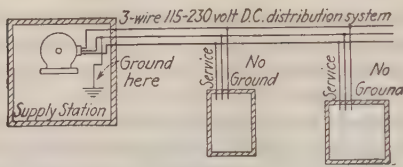
2. For a-c systems there must be a ground at the secondary of the transformer supplying the system. There must be another ground at each building service on the supply side of the service switch.

3. For two or more buildings served by a master service the ground must be located at each building utilizing two or more branch circuits or if the building houses livestock.

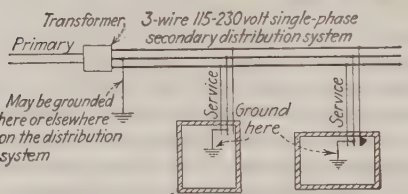
4. For an isolated system which is not connected to an exterior distribution system the ground is made at the source of supply or at the switchboard on the supply side of the first switch controlling the system.

250. The Conductor to Be Grounded:

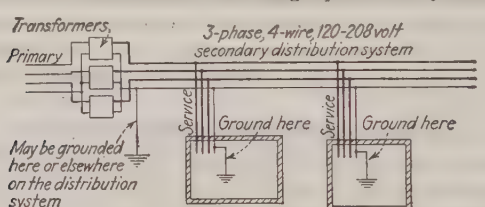
Kind of System	Conductor Grounded
. For all two-wire, d-c systems	Negative conductor
. For two-wire, a-c systems	Either conductor as long as all grounds are on the same respective conductor of the system
. For three-wire, single-phase, a-c systems and three-wire, d-c systems	Neutral conductor
. For multiphase systems without a common conductor	Any conductor as long as all grounds are on the same respective conductor of the system
. For multiphase systems having one conductor common to all phases	Common neutral conductor
. For multiphase systems with one phase connected single phase, three wire	Neutral conductor of the three-wire phase. Only one phase can be so used



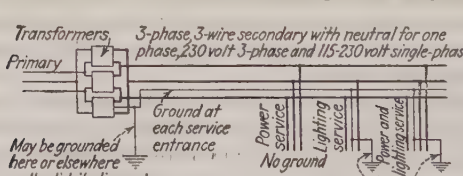
I. Three-wire 115–230 volts d-c system.



II. Three-wire 115–230 volts single-phase a-c system.



III. Four-wire 120–208 volts three-phase a-c system.



IV. Four-wire 230 volts three-phase a-c system with one phase arranged three-wire, 115–230 volts.

FIG. 188.—Location of system grounds. (*National Electrical Code Handbook.*

250A. The non-current-carrying parts of fixed equipment are considered to be satisfactoily grounded under any one of the following conditions:

1. If metallically connected to grounded cable armor or the grounded metal enclosure of conductors. This is the common and preferable method.

2. By a grounding conductor run with circuit conductors in wire assemblies; this conductor may be uninsulated, but if an individual covering is provided for this conductor it shall be finished to show a green color.

3. By a separate grounding conductor installed the same as a grounding conductor for conduit and the like.

4. By special permission, other means for grounding fixed equipment may be used.

250B. The non-current-carrying parts of portable equipment are considered to be satisfactorily grounded under any one of the following conditions:

1. By means of the metal enclosure of the conductors feeding such equipment, provided an approved multiprong plug or equivalent is used, one prong for the purpose of grounding the metal enclosure, and provided, further, that the metal enclosure is attached to the plug and to the equipment by connectors approved for the purpose.

2. By means of a grounding conductor run with the circuit conductors in wire assemblies, provided an approved multiprong plug or equivalent is used, one prong for the purpose of connecting such grounding conductor to the grounded metal raceway or cable armor; this conductor may be uninsulated, but if an individual covering is provided for this conductor it shall be finished to show a green color.

3. By means of a separate flexible wire or strap, insulated or bare, protected as well as practicable against mechanical injury.

250C. The continuity of the ground of metal enclosures for conductors must be assured by one of the following means (see also following paragraphs for additional requirements for services and hazardous locations):

1. Threadless fittings, made up tight, with conduit, armored cable, or electrical metallic tubing.

2. Two lock nuts, one inside and one outside of boxes and cabinets.

3. Threaded fittings with joints made up tight, where rigid conduit is involved.

4. Tightly fitting or bolted joints between sections of metal raceway, wireway, or bus way.

5. Bonding jumpers of copper or other corrosion-resistant material fastened to the enclosure with an approved clamp or fitting and having a carrying capacity not less than is required for the grounding conductor.

6. Other devices (not lock nuts and bushings) approved for the purpose.

The electrical continuity of service equipment and service-conductor enclosures from overhead distribution systems must be assured by one of the means 1, 3, 5, or 6 as given above for grounding of general conductor enclosures. With service cable having an uninsulated grounded service conductor in continuous electrical contact with its metallic armor or tape, the metal covering is considered to be adequately grounded.

Service conduit or metal pipe from underground supply is considered to be grounded if it contains metal-sheathed cable bonded to a continuous underground metal-sheathed cable system. The sheath or armor of service cable from underground supply is considered to be grounded if

it is metallically connected to a continuous underground metal-sheathed cable system.

In hazardous locations, regardless of the voltage involved, the electrical continuity of metallic raceway, boxes, and the like shall be assured by one of the methods specified in 1, 3, 5, or 6 as given above for grounding of general conductor enclosures.

251. The equipment and conductor-enclosure ground should be located as close to the service entrance or source of supply as practicable This ground must be so located that no conductor enclosure is grounded through a grounding conductor smaller than required by Table 254. A common method is to run the equipment ground from the service-switch enclosure. So far as practicable all other equipment is then connected to ground by electrically continuous conductor enclosures from the service switch. Bonding jumpers or ground wires are used to connect isolated equipment to grounded equipment. In rare cases separate equipment grounds may be run where the equipment is located a considerable distance from other grounded equipment.

252. The method of grounding is to run a grounding conductor from the locations specified in Secs. **249** to **251** to a grounding electrode (Sec.

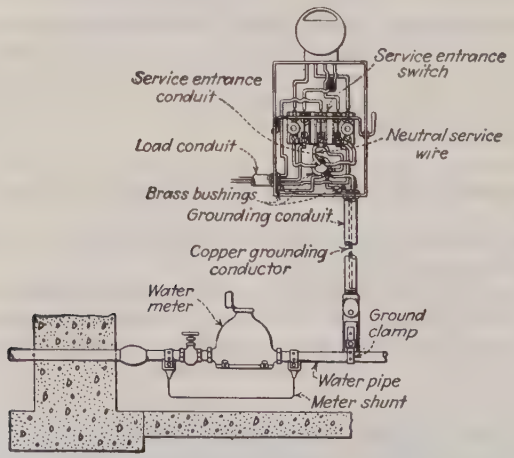


FIG. 189.—Typical ground connection. (*Crouse Hinds Co.*)

255) which is in contact with the ground. A common method is to run the system grounding conductor inside a metal enclosure which serves as the equipment and conductor-enclosure grounding conductor (Fig. 189). Refer to Sec. **257** for discussion of common grounding conductors.

253. Size of System Grounding Conductor.—1. For d-c systems not smaller than the largest conductor supplied by the system and in no case smaller than No. 8.

2. For a-c systems grounded to artificial driven pipe or rod grounds or to a buried plate ground: No. 8 if the service conductors are No. 2 or smaller, No. 6 if the service conductors are larger than No. 2.

3. For a-c systems grounded to an underground piping system or to the metal frame of the building:

Size of largest service conductor, No. or cir. mils	Size of copper[a] ground wire, No.	For service equipment ground	
		Size of conduit, in.	Size of electrical metallic tubing, in.
p to 2	8	½	½
or 0	6	½	1
/0 or 3/0	4	¾	1¼
/0–350,000	2	¾	1¼
50,000–600,000	0	1	2
00,000–1,100,000	2/0	1	2
ver 1,100,000	3/0	1	2

[a] May be of other corrosion-resistant material of equivalent resistance and tensile rength.

254. Size of Equipment and Conductor-enclosure Grounding Conductor

ating or setting of automatic rercurrent device in circuit head of equipment, conduit, etc., maximum amp.	Size of grounding conductor		
	Copper wire No.,	Conduit or pipe, in.	Electrical metallic tubing, in.
20	16[a]	½	½
30	14	½	½
40	12	½	½
60	10	½	½
100	8	½	½
200	6	½	1
400	4	¾	1¼
600	2	¾	1¼
800	0	1	2
1,000	2/0	1	2
1,200	3/0	1	2

[a] Permissible only when part of an approved cable assembly.

NOTE.—If connection is to an artificial ground as listed in Sec. **255** (5), the grounded nductor need not be larger than No. 6 copper.

255. The grounding electrode may be:

1. A continuous metallic underground water-piping system must be used where available. Connection must be made on the street side of the meter, or a bonding jumper of a size not less than required for the grounding conductor must be installed to by-pass the meter and service unions.

2. A local metallic underground piping system, metal well casing, etc.

3. The metal frame of the building, provided the building is grounded effectively.

4. A continuous metallic underground gas-piping system; connection must be on the street side of the meter.

5. An artificial ground consisting of a driven pipe or rod or a buried plate.

a. The pipe must be not less than ¾ in. electrical trade size and be of nonferrous metal or galvanized. The pipe must be driven at least 8 ft. deep unless rock bottom is encountered or, if rock buttom is encountered at less than 4 ft. an 8-ft. length must be laid in a trench.

b. The rod must be not smaller than ⅝ in. if of steel or iron, or ½ in. if of approved nonferrous material.

c. The plate must be not less than 0.06 in. thick for nonferrous metal and not less than ¼ in. thick for iron or steel. The plate must present at least 2 sq. ft. of surface to exterior soil.

NOTE.—The ground resistance on an artificial ground must be not less than 25 ohms measured as explained in Sec. 175, Div. 8. Such a ground must not be used for both an interior wiring system and lightning rods.

6. Railway track when the wiring system is supplied from the railway circuit.

256. Protection of Grounding Conductor.—1. The conductor may be either bare or insulated.

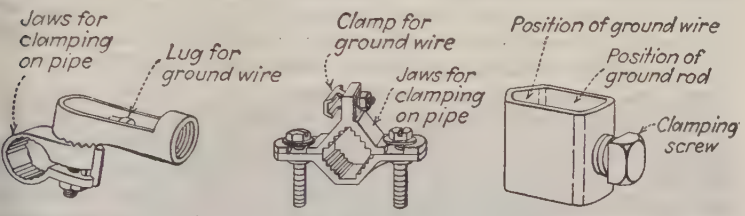
2. If No. 8 and smaller, the grounding conductor must be enclosed in armored cable, conduit, or electrical metallic tubing.

3. If No. 6 and larger, the grounding conductor may be stapled to the building surface.

257. The same grounding conductor may be used for the system ground and the equipment or conductor-enclosure ground, provided the size is as large as required for each alone. If desired, the system ground may be made with one wire and the equipment ground with another wire or conduit or tubing.

258. The grounding conductor must be connected to the grounding electrode with an approved type of bolted cast-metal clamp, or with a pipe fitting threaded into the pipe, or with other equally substantial approved means. The connection for the grounding conductor must be of a type that does not require soldering. Figure 190 shows some types of grounding clamps. For the smaller ground wires, which must be enclosed in conduit, the type in Fig. 190, I is used. For bare ground

wire connected to a water or gas pipe, use the type in Fig. 190, II. The type in Fig. 190, III is for a bare wire to be attached to a ground rod. For connecting the other end of the grounding conductor to either the circuit wire or the metal equipment, solderless pressure connectors should be used.



I- For pipe connection with ground wire in conduit (General Electric Supply Co.)

II- For pipe connection with bare ground wire (Westinghouse Electric Supply Co.)

III- For rod connection with bare ground wire (Copperweld Steel Co.)

FIG. 190.—Ground-wire clamps.

259. On grounded wiring systems the conductor which is connected to ground must be identified throughout the system. For conductors of No. 6 and smaller the identification characteristic must be a white or natural gray finish of the braid covering the wire. For conductors larger than No. 6 the insulation at the end of the conductor at terminals may be painted white when installed, or the entire outer finish of the wire covering may be white as for the smaller conductors. All ungrounded conductors must be finished in black or red or any color contrasting with white. At the terminals of wiring devices the grounded conductor must be connected to the nickel- or zinc-colored terminal. On screw-shell devices the grounded conductor must be connected to the screw shell itself. No single-pole switch or circuit breaker and no fuse shall be used in a grounded conductor.

SERVICE-ENTRANCE REQUIREMENTS AND INSTALLATION

260. Service entrance for the electrical system of a building may be made by means of overhead or underground service conductors. A service consists of the service conductors and the service equipment. The service conductors are the conductors which supply a building with electrical energy from an electric power system outside the building. They consist of that portion of the supply conductors which extend from the street distribution main or distribution transformer to the service equipment of the building. The service conductors may be located overhead or underground. For overhead conductors the service conductors include the conductors from the last line pole to the service equipment.

The service conductors of an overhead service are further classified into two parts: the service-drop conductors and the service-entrance conductors. The **service-drop conductors** are the portion of the overhead service conductors between the last line pole and the first point of attachment to the building. The **service-entrance conductors** of an overhead service are that portion of the service conductors between the service equipment and a point outside the building, clear of the building walls, where they are joined to the service-drop conductors.

261. The service equipment must consist of an externally operated disconnecting device and overcurrent protective device.

The disconnecting device must provide a readily accessible means for disconnecting all the service conductors from the source of supply. It may consist of a single switch or manually operated circuit breaker or, in the case of a multiple-occupancy building, not more than six switches or six manually operated circuit breakers. In Fig. 191, if there had been only six occupants in the building, the master service switch would not have been required. In multiple-occupancy buildings each occupant must have access to his disconnecting means. Circuit breakers may be equipped with electrical remote control, provided that the breaker has in addition a manually operable handle. The disconnecting means must be of a type which will plainly indicate whether it is in the open or closed position. The service switch or breaker must be located as close as is feasible to the point of entrance of the service conductors to the building. It may be located either outside or inside the building. If the switch or breaker does not open the grounded conductor, other means must be provided at the service entrance for disconnecting the grounded conductor of the supply from the interior wiring. The connection to a neutral terminal bar in the service switch will constitute a satisfactory disconnecting means.

A service switch must have a rating which is not less than the fuse holder in series with it, and the rating must be at least as great as the minimum allowable load (refer to Sec. **59** of Div. 3). Except in special cases of very small occupancies, it is not good practice to install a service switch that has a rating less than 60 amp. or a service circuit breaker with a rating less than 50 amp. A 30-amp. switch should not be used for a two-wire service supplying more than two 15-amp. branch circuits.

Each ungrounded service conductor must be provided with overcurrent protection. The protection may consist of a single set of fuses or circuit breakers or, in the case of a multiple-occupancy building, not more than six sets of fuses or six circuit breakers. For rating of fuses or setting of circuit breakers, refer to Secs. **222** and **223.** No overcurrent device shall be inserted in a grounded conductor except a circuit breaker which simultaneously opens all conductors of the service. The protective devices must be located at the same point as the disconnecting means unless located at the outer end of the service raceway.

In addition to the disconnecting means and the protective devices, when the building is supplied directly from public-utility mains, the service equipment will include the kilowatt-hour meter for the measurement of the power consumption. For small or multiple-occupancy buildings, the branch-circuit distribution equipment frequently is also grouped along with the service equipment (see Fig. 191). If the service overcurrent protective devices are locked or sealed, or otherwise not readily accessible, the branch-circuit overcurrent devices must be

IG. 191.—Arrangement of meters and service for a multi-tenant building.

nstalled as close as is practicable to the load side of the service equipment. They must be in an accessible location, and be of a lower rating han the service overcurrent device.

The construction and types of service equipment are discussed under witches in Div. 4.

262. There are six possible different arrangements or sequences for ervice equipment consisting of switch, fuses, and meter, as follows:

1. Switch-fuses-meter.
2. Switch-meter-fuses.
3. Fuses-switch-meter.
4. Fuses-meter-switch.
5. Meter-switch-fuses.
6. Meter-fuses-switch.

When circuit breakers are employed there are, of course, only two possible sequences: meter-circuit breaker or circuit breaker-meter.

The proper order for placing the switch, fuses, and meter in the circuit has been the subject for much dispute and not enough standardization, each power company reserving for itself the decision on the proper method. Each method has its advantages, and it has been a matter for local decision as to which advantage seems most important to the individual power company. Sequences 1, 3, and 4 are allowed by the National Electrical Code under any condition. Sequences 2, 5, and 6 are permitted only on a-c systems of a voltage not greater than 300 between conductors.

The switch-fuse-meter sequence (Fig. 192, II) was the most common prior to 1935. This sequence has the meter protected by the main fuses

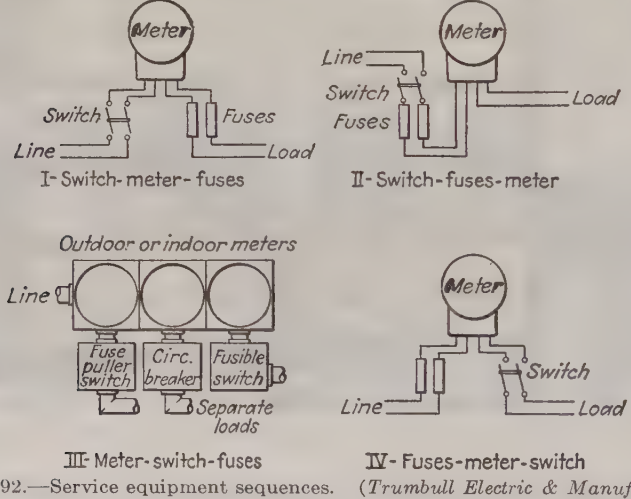


FIG. 192.—Service equipment sequences. (*Trumbull Electric & Manufacturing Co.*)

in case of short circuit in the meter wiring, but, if the switch is sealed, service calls for replacing main fuses are more frequent, or, if the switch is not sealed, current diversion is possible. Both of these disadvantages were a source of expense to the power company and led to the trial of other sequences. The switch-meter-fuse sequence (Fig. 192, I) has the advantage that the service switch disconnects the meter from the supply, and, if the switch is sealed, access to the unfused line wires and theft of current is prevented, and at the same time the customer is given access to the main fuses. The fuses-switch-meter sequence generally is not employed unless it is desired to locate the fuses at the outer end of the service raceway. Even then it is best to use additional fuses of s

ower rating at the point of location of the service switch so that these uses will blow before the outside fuses, which are not easily accessible. The fuses-meter-switch sequence (Fig. 192, IV) is given as a matter of historical interest, but it is little used at present. Its advantage was that he main fuses protected the meter and provided convenient means for esting the meter without interrupting the customer's service. The uses were usually sealed, however, and were therefore a source of service alls as explained above, and the switch was of no advantage as far as lisconnecting the meter and fuses were concerned. The meter-switch-uses sequence is very convenient for outdoor metering, making theft f current practically impossible and saving time for the meter reader, hrough his not having to go inside the building or make repeat calls hen the customer is not at home. The meter can be removed from the ocket without interrupting the supply, and the only disadvantage is hat the meter is not protected by the fuses. This has not proved to be a erious difficulty, and the trend is toward the standardization of this equence, which is also readily used with multimetered services as shown n Fig. 192, III and Fig. 191. The meter-fuses-switch sequence is very eldom used, since it generally does not have any advantage over the neter-switch-fuses sequence.

263. A master service is a service which supplies more than one uilding under single management. If the buildings are supplied from

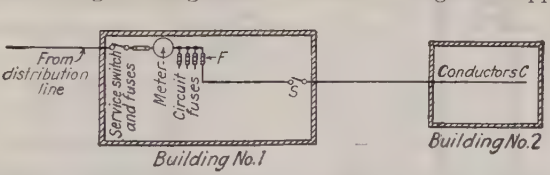


Fig. 193.—Two buildings under single management. No service fuses are quired in building No. 2 if fuses *F* are of proper rating to protect conductors . A switch *S* must be installed to control conductors *C*. Switch *S* may be building No. 1 if accessible to persons using building No. 2; otherwise it ust be in building No. 2. (*National Electrical Code Handbook.*)

private distribution system, the services should be installed in accord-nce with the general requirements for services from a public utility. those installations which include properties with their own generating ant, the conductors running from one building to another are not con-dered as service conductors.

The supply to each building must be separately controlled and properly otected by overcurrent devices. The control should consist of an ternally operable enclosed safety switch or a circuit breaker. The ntrol may be located in the building served or in another building, ovided that it is accessible to persons using the installation. Garages d outbuildings of residences and farms come under this class of installa-on. Methods of meeting these requirements are illustrated in Figs.

193 and 194. Although not required and not shown in the figures, it i best practice to equip each building with its own individual control an protection located inside the building itself. The protection for eac building should have a lower rating or setting than the protection at

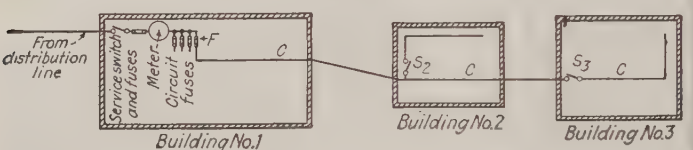


FIG. 194.—Three buildings under single management. If properly pr tected by fuses F, conductors C require no other fuse protection. A switc S_2 must be provided to control the wiring in building No. 2, and a switc S_3 to control the wiring in building No. 3. Switch S_3 may be in eithe building No. 1 or building No. 2 if readily accessible to persons using buildin No. 3. (*National Electrical Code Handbook.*)

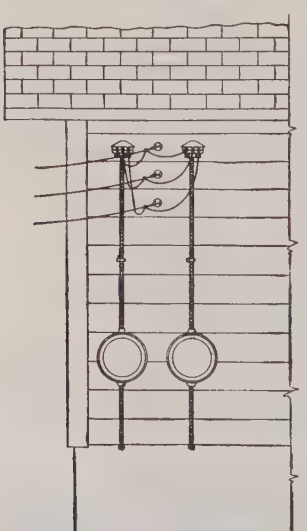


FIG. 195.—Two sets of service-entrance conductors tapped from one service drop. (*National Electrical Code Handbook.*)

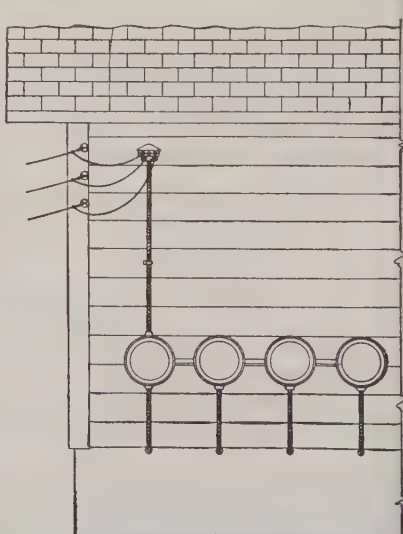


FIG. 196.—Four sets of service-entranc conductors tapped from one set of ma service conductors. (*National Electric Code Handbook.*)

in the figures, so that in case of trouble the protection of any one buildin will function without operating the device at F.

No service should supply one building from another unless they a under the same management.

264. No building should be supplied by more than one set of service conductors from the same secondary distribution system or from the same transformer except as follows:

1. **Fire Pumps.**—If a separate service is required for fire pumps.

2. **Emergency Lighting.**—If a separate service is required for emergency lighting purposes.

3. **Capacity Requirements.**—If capacity requirements make multiple services desirable.

4. **Buildings of Large Area.**—By special permission, if more than one service drop is necessary owing to the area over which a single building extends.

5. **Multiple-occupancy Buildings.**—By special permission, in multiple-occupancy buildings where there is no available space for service equipment accessible to all the occupants.

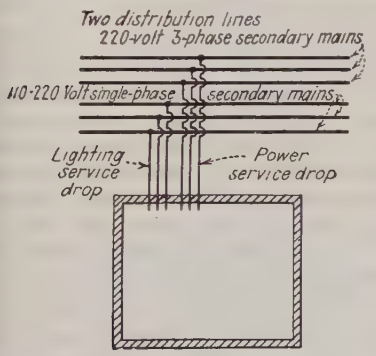


FIG. 197.

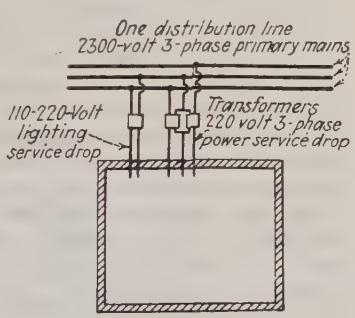


FIG. 198.

6. **Buildings of multiple occupancy** may have two or more separate sets of service-entrance conductors which are tapped from one service drop (Fig. 195), or two or more sub-sets of service-entrance conductors may be tapped from a single set of main service conductors (Figs. 191 and 196).

7. Where additional services are required for different classes of use, such as needs for different voltage, frequency, or phase, or different rate schedules for different types of use of electric power.

Separate services may be brought into a single building for power and light respectively, when the lighting is supplied from a separate secondary distribution main as shown in Fig. 197.

Separate services may be brought into a single building for power and light, respectively, if each service is supplied through a separate transformer (Fig. 198) or if the lighting service is supplied from one transformer of a polyphase bank of transformers supplying the power.

265. Size of Service Conductors.—Service conductors must have a current-carrying capacity sufficient to supply the load of the building (refer to Div. 3) and regardless of the actual load must have a current-carrying capacity not less than that required by the minimum load requirements of Div. 3. Also, regardless of the load, no wire should be smaller than the following minimum sizes:

Conductors	Minimum Allowable Size
Service entrance for all installations, except ones supplying a single branch circuit.	No. 6, except No. 8 by special permission or if supplying only two 2-wire branch circuits
Service entrance supplying a single branch circuit.	No. 12 (but in no case smaller than size of branch circuit supplied)
Service drop	No. 10 for soft-drawn copper; No. 12 for medium or hard-drawn copper
Service of over 600 volts	No. 6, except that in multiconductor cables No. 8 may be used

266. Installation of Overhead Services.—The conductors for service drops may consist of approved multiconductor cable (see Div. 2) or of open individual conductors which are rubber- or thermoplastic-insulated or of weatherproof type. At the pole, open conductors are dead-ended on an insulator rack or on insulators mounted on a crossarm separate from the crossarm supporting the distribution main (see Figs. 57 and 68 of Div. 8). Multiconductor cable is supported with a special cable clamp fastened to a secondary rack as shown in Figs. 201, 202, and 203. At the building, open conductors are dead-ended on cable racks (Fig. 199, I), on pin-type insulators (Fig. 200), or by means of strain insulators (Fig. 199, II). At the building, multiconductor cables are supported by means of special cable clamps fastened to cable hooks mounted on the building wall, as shown in Figs. 201, 202, and 203*A*. Service drops must have a distance of not less than 8 ft. between any point of the roof of a building over which they pass and must have a clearance of not less than 36 in. from windows, doors, and porches. It is best not to support the conductors from roofs of buildings, but, where such support is necessary, the supports should be of substantial construction. The National Electrical Code requires that, in general, the point of attachment of a service drop to a building shall be not less than 10 ft. above ground and shall be at a height to permit a minimum clearance for the conductors of 10 ft. above sidewalks and 18 ft. above driveways, alleys, and public roads. The attachment should not be more than 30 ft. above ground unless necessary for proper clearance. Where the form of the building will not permit the above clearances, the attachment may be less than 10 ft. provided at least 12 ft. clearance is obtained over residential garage driveways, all other clearances are obtained, and all conductors and connections within 8 ft. of the ground are properly insulated with rubber or equivalent insulation.

The service-entrance conductors may consist of open individual con-

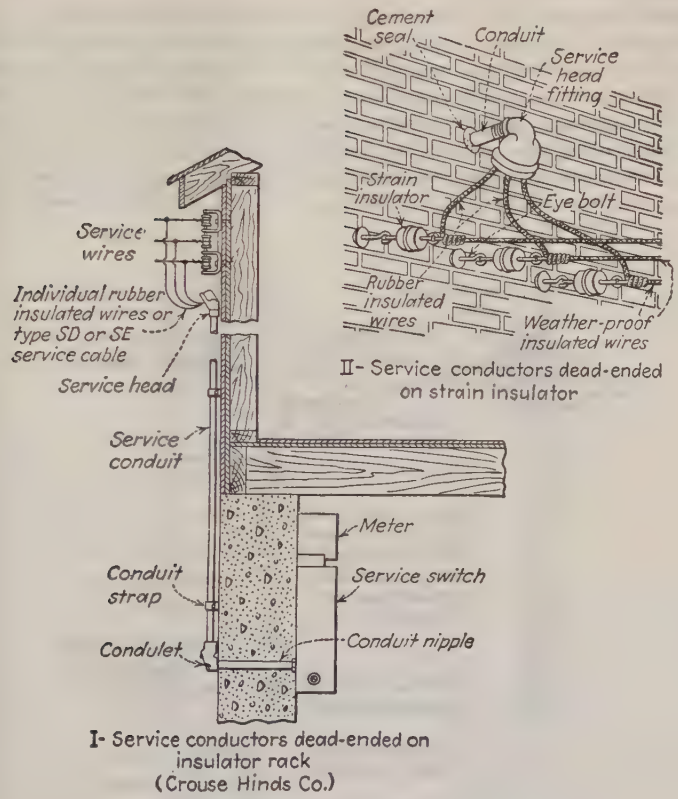


FIG. 199.—Conduit service entrances with indoor meter.

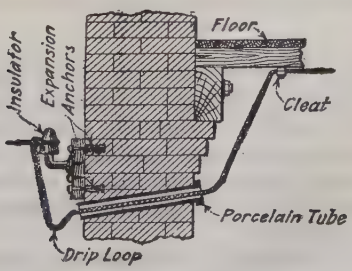


FIG. 200.—Service entrance; mill-construction building.

ductors within not less than 8 ft. of the ground, multiconductor cable of approved type (see Div. 2) not protected by conduit, multiconductor cable of approved type protected by conduit, or individual conductors run in rigid conduit, or, for circuits not exceeding 600 volts, in electrical metallic tubing. Open conductors of the weatherproof type may be extended along the exterior of buildings supported on insulators or insulator racks, provided they are more than 8 ft. from the ground, 3 ft. from windows, doors, and porches, and are not exposed to mechanical

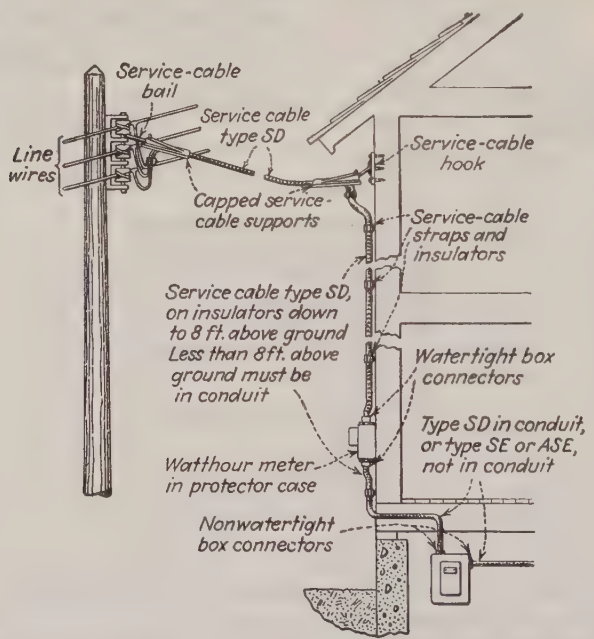


FIG. 201.—Typical service installation using type SD cable without an entrance cap.

injury. The supports should be spaced not more than 9 ft. apart and should maintain a separation of at least 6 in. between conductors and 2 in. from the surface of the building, or should be spaced not more than 15 ft. apart and maintain a separation of at least 12 in. between conductors, or, for systems with a voltage between conductors of not more than 300 volts, may be spaced not more than 4½ ft. apart and maintain a separation of at least 3 in. between conductors.

If open wires enter a building, they must be rubber covered at the point of entrance and be brought in through individual noncombustible, nonabsorptive, insulated tubes or approved roof bushings. The tube

should be slanted downward toward the outside of the building and be cemented in the wall. A drip loop must be formed on the conductors on the outside of the wall before entering the tubing. Proper construction is illustrated in Fig. 200.

Multiconductor service cables which are approved for mounting in contact with the building wall (Types SE and ASE) are supported by means of one-hole cable clamps similar to one-hole conduit straps. The clamps must be spaced at intervals not exceeding 4½ ft. Multicon-

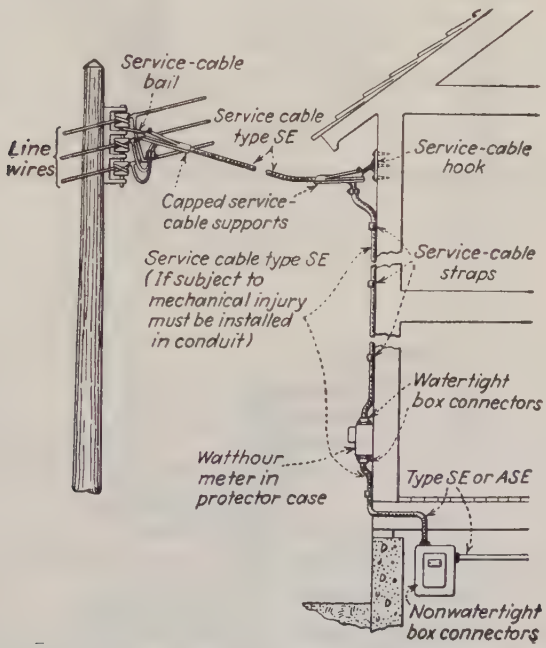


Fig. 202.—Typical service installation using Type SE cable without an entrance cap.

ductor service cables which are not approved for mounting in contact with the wall (Type SD) must be supported on insulating supports spaced at intervals not exceeding 15 ft. and maintain a distance of at least 2 in. from the surface wired over.

The National Electrical Code requires the following conditions to be met where service-entrance conductors are joined to the service-drop conductors. Service raceways shall be equipped with a raintight service head. Service cables, unless continuous from pole to service equipment or meter, shall be equipped with an approved raintight service head or be formed in a gooseneck, taped and painted, and held securely in place

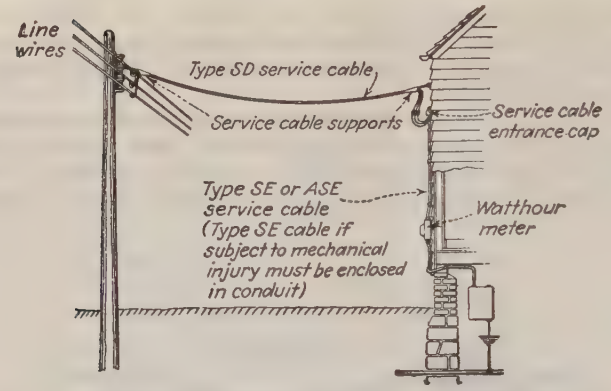


FIG. 203.—Typical service installation using Type SD and Type SE or ASE cable.

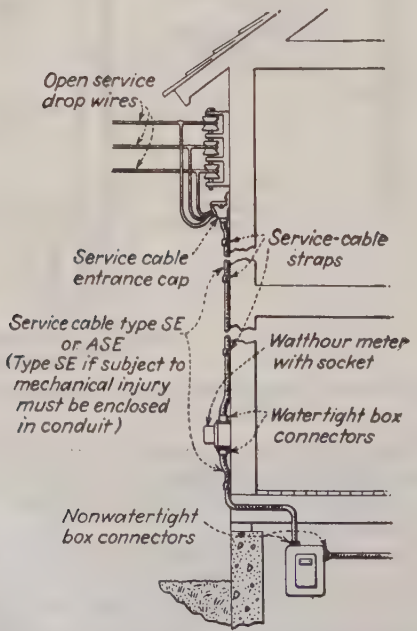


FIG. 203A.—Typical service installation using open individual service-drop conductors and Type SE or ASE service-entrance cable. (*General Electric Co.*)

by its connection to service-drop conductors below the gooseneck or by a fitting approved for the purpose. Drip loops shall be formed on individual conductors.

267. Installation of Underground Services.—The service conductors for underground services may consist of parkway cable, nonmetallic-armored cable, or multiconductor service cable Type USE buried directly in the ground, or of any of the above types of cable or lead-sheathed cables installed in conduit or underground ducts. The insulation of the lead-sheathed cables may be rubber, thermoplastic, varnished cambric, or paper. The National Electrical Code requires the conductors to be protected where entering the building as follows: Where underground service conductors enter a building, they shall have mechanical protection

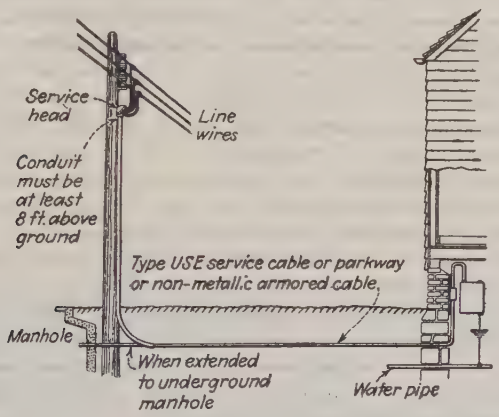


FIG. 204.—Underground service from an overhead line. (*Anaconda Wire & Cable Co.*)

in the form of rigid or flexible conduit, electrical metallic tubing, auxiliary gutters, the metal tape of an approved service cable, or other approved means. The mechanical protection shall extend to the enclosure for the service equipment unless the service switch is installed on a switchboard, in which case a bushing shall be provided which, except where lead-covered conductors are used, shall be of the insulating type. Where a service raceway or duct enters from an underground distribution system the end within the building shall be sealed with suitable compound so as to prevent the entrance of moisture or gases. If the cables are carried up a pole, they must be protected against mechanical injury to a point at least 8 ft. above the ground. Conduit is generally used for this protection, and a much neater appearance is obtained if the conduit is carried up the pole to the point of connection to the distribution main as shown in Fig. 204.

268. Splicing of Service Conductors.—Service conductors shall be without splices except as follows:

1. At point of tap connection to distribution main.
2. At point of junction of service-drop and service-entrance conductors.
3. Clamped or bolted connections in a meter enclosure are permitted.
4. Taps to main service conductors are permitted as provided in subparagraph 6 of Sec. **264.**
5. A connection is permitted, if properly enclosed, where an underground service conductor enters a building and is to be extended to the service equipment or meter in another form of approved service raceway or service cable.
6. A connection is permitted where service conductors are extended from a service drop to an outside meter location and returned to connect to the service-entrance conductors of an existing installation.

269. Typical service installations of proper construction are shown in Figs. 199 to 204. Overhead services to occupancies having relatively small loads, such as residences and small stores, are generally made with one of the installations shown in Figs. 199, I, 201, 202, 203, and 203*A*. The installation of Fig. 199 represents the older type of construction employing open service-drop conductors and individual service-entrance conductors enclosed in rigid conduit, with the service equipment located in the cellar of the building. The present trend is toward installations of the types shown in Figs. 201, 202, and 203. They employ multiconductor service cable with the meter mounted in a weatherproof housing on the outside of the building about 5 ft. above the ground. Installations of this type are superseding the older type, owing to their lower first cost, neater appearance, ease of installation, and difficulty of current diversion. Frequently the service switch is also mounted outside the building along with the meter.

In congested city residential districts an underground service using underground service-entrance cable is frequently run from overhead lines (Fig. 204), where a change to underground distribution is planned at a later date. This procedure facilitates the change-over, as the part of the cable which is above ground may in the future be taken down and placed underground and run directly into the underground distribution box. In cities where the distribution is all underground, lead-covered cable in rigid metal conduit is the most common method of running services. The advantage of this system is that, in case the service needs to be replaced for any reason, the cable may be pulled out of the conduit and another one installed without having to dig up the pavement or sidewalk. For apartment-house service a meter trough is installed in which are mounted the meter sockets, one for each apartment, in one or more horizontal rows (Fig. 191). Directly under each meter is a branch-circuit distribution panel containing fuses or circuit breakers for the branch-circuit protection for the apartment. In some cases a service

switch is provided for each apartment, and a feeder is run to the apartment with the branch-circuit distribution panel located in the apartment.

For moderate-sized industrial buildings a service frequently is installed as shown in Fig. 199, II. The service-entrance conductors are individual rubber-insulated wires. The conduit is carried down the inside of the building wall to the point of location of the service equipment. For industrial buildings with heavier loads the type of construction shown in Fig. 200 is often employed.

Types of Construction for Overhead Service Installations

Type	Service-drop conductors	Service-entrance conductors	Illustration
1	Open individual rubber-insulated or weatherproof-type conductors	Individual rubber-insulated wires in conduit	Fig. 199, I
2	Same as 1	Type SD service cable in conduit	Fig. 199, I
3	Same as 1	Type SE service cable in conduit	Fig. 199, I
4	Same as 1	Type SE service cable mounted directly on wall with cable straps	Fig. 203*A*
5	Same as 1	Type ASE service cable mounted directly on wall with cable straps	Fig. 203*A*
6	Type SD service cable (the service-drop and service-entrance conductors consist of one continuous length of Type SD cable)	Type SD service cable mounted on wall by means of insulators. Wherever less than 8 ft. from ground must be enclosed in conduit	Fig. 201
7	Type SE service cable (the service-drop and service-entrance conductors consist of one continuous length of Type SE cable)	Type SE service cable. If subject to mechanical injury must be enclosed in conduit	Fig. 202
8	Type SD service cable	Type SE service cable. If subject to mechanical injury must be enclosed in conduit	Fig. 203
9	Same as 8	Type ASE service cable mounted directly on wall with cable straps	Fig. 203

270. For commercial or industrial services the maximum demand is usually metered as well as the kilowatt hours. Where the demand is of the order of a few kilowatts, this may be done with a single meter which has a demand-indicating pointer as well as the usual meter dials (Fig. 205). For larger installations a separate indicating-demand meter is installed (Fig. 206). A recording type of demand meter may also be employed for installations of more than about 150 amp.; current trans-

formers are usually required in order to reduce the current which the meter has to handle. If the voltage is more than 250 volts, potential transformers are also required. For an underground service from an urban network system, the service equipment consists of a main fused switch or circuit breaker, a set of current transformers in a sheet-metal cabinet, and meters as outlined above. If the supply comes from a radial feeder system, a transformer bank with an oil circuit breaker and disconnect switches is installed at the building ahead of the above service equipment. For an overhead service a transformer bank is installed just outside the building, on a concrete foundation on the ground or on an elevated platform between two poles. The bank will contain high-voltage fuses and lightning arresters in addition to the transformers. The service conductors are then brought into the building in conduit or as individual wires to the service equipment. Sometimes the metering is installed so as to measure the input to the transformers so that the customer pays directly for the transformer losses. When this is done high-voltage current and potential transformers are installed in the leads to the primary of the transformers. The meters may then be located in a weatherproof cabinet outside the building or located inside the building wall, as before, with a conduit to carry the secondary leads from the instrument transformers.

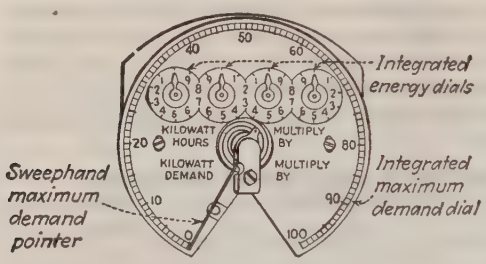


FIG. 205.—Dial for a watthour meter with demand-indicating pointer. (*Westinghouse Electric & Manufacturing Co.*)

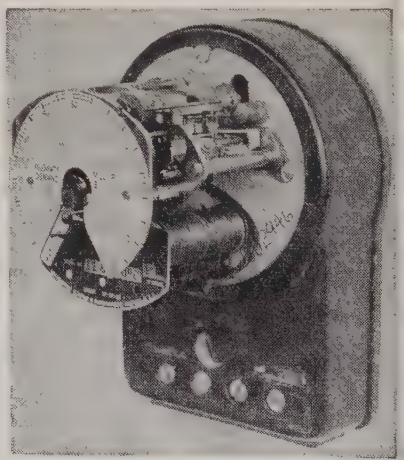


FIG. 206.—Indicating-demand meter. (*Westinghouse Electric & Manufacturing Co.*)

CRANE WIRING

271. Wiring for cranes consists of the following elements:

1. Collector switch.
2. Main collector conductors.

3. Cab main-line switch.
4. Bridge collector conductors.
5. Motor-circuit wiring.

272. A collector switch or circuit breaker must be installed in every circuit feeding crane wires. A fused switch is most frequently used to provide overload protection, although in important installations, where reliability is essential—where equipment must be placed back in service after an accident, in minimum time—circuit breakers are used. From an electrical standpoint the best location for the switch is at the center of the run.

It must be readily operable from the ground, be within sight of the collector conductors, and be of a type which can be locked in the open position. The capacity of the switch must not be less than the values given in Sec. **283** for a cab switch.

273. The main collector conductors are bare copper trolley wires or structural-steel conductors that are erected parallel to the crane runway. The location of the conductors is determined by conditions. Sometimes the crane builder specifies that the conductors must be located in a certain position; and in other cases the purchaser selects and specifies the position of the conductors, and the crane manufacturer arranges the current collectors on the crane accordingly.

274. Trolley wire for cranes is hard-drawn copper, the same as used in electric traction. Hard-drawn wire must be used to prevent excessive stretching. Round wire is erected where the method of support adopted does not involve the use of trolley ears for holding it at intermediate points between the ends of the run. Where trolley ears are used figure-eight or, preferably, grooved trolley wire should be used, because it can be readily held in screw-clamp trolley ears. Round wire can be used with trolley ears, but the ear flanges of these must be hammered down around the wire, a time-consuming operation requiring some skill; also, a round-wire ear introduces a hump on the wire and makes the trolley wheel jump and draw an arc when the wheel passes over the raised place. Either 0, 2/0, 3/0, or 4/0 wire is usually required. The wire size required is ordinarily specified by the crane builder, but in any case it should be large enough so that the voltage drop in it will not much exceed 3 or 4 per cent of the line voltage with all the crane motors operating at full load. In no case should the wires be smaller than the minimum allowable sizes given in Sec. **284** for bridge collector conductors.

275. Trolley rails of structural steel are being used to some extent instead of copper trolley wire to supply current to cranes and other moving electrical machinery. The steel rails are made sufficiently heavy so that they cannot break and fall as copper wires occasionally do. Sometimes strap steel bars are used, but more frequently a section is adopted, such as an angle or a tee, which has considerable stiffness in all directions. Steel conductors should be painted, except on the contact edge or face, to prevent corrosion. Either a shoe or a trolley wheel can

be used to collect current from a steel conductor rail. A shoe or spoon, which makes a rubbing contact, is probably preferable for the average application. Trolley-wheel collectors that travel at high speeds are not successful for current collection from steel conductors, because the wheel tends to bounce and jump from the rigid rail at joints and uneven places.

276. The main collector conductors must be isolated by elevation or provided with suitable guards so that persons cannot inadvertently touch the live parts while in contact with the ground or with conducting material connected to the ground. If the crane travels over easily ignitible combustible fibers and materials the collector conductors must be protected by barriers so arranged as to prevent the escape of sparks or hot particles. Probably the best location for the collector conductors on a bridge-crane runway is between the flanges of and parallel to one of the crane girders. Here the conductors are out of the way and well protected and can be readily supported. It is not often that they are erected in any other position. Occasionally the trolley wires can be supported from the roof trusses above the crane runway and are installed similarly to the trolley wires for trolley cars. A pole collector with a wheel at its upper end, exactly like a trolley-car pole but much shorter, is used. Where the spacing between roof trusses is very great this method may not give good results, because of the wire swinging and the trolley coming off. The collector conductors, when carried along runways, should normally be supported on insulating supports at intervals not exceeding 20 ft. and separated from each other at least 8 in. if mounted in a vertical plane or 6 in. if mounted in a horizontal plane except that a horizontal spacing of not less than 3 in. may be used for monorail hoists. If wires are used they should be secured at the ends with approved strain insulators and so mounted on intermediate insulators that the extreme displacement of the wires will not bring them closer than 1½ in. from the surface wired over. Where necessary the intervals between supports may be increased up to 40 ft., provided that the separation between conductors is increased proportionately. All sections of the conductors must be so joined that a continuous electical connection is provided. The collector conductors must not supply any equipment other than that of the crane or cranes which they are designed to serve.

277. Methods of supporting crane trolley wires differ with conditions. If the crane is provided with hook-shoe collectors (Fig. 207), which slide along under and carry the weight of the trolley wire, the wire is rigidly held only at the terminations at the ends of the run and is kept from sagging by intermediate, insulating brackets, like those shown in Fig. 207. If trolley-wheel current collectors are used (and they probably provide the best means of collecting current), the tension in the wire is taken by the terminations, and the wire is also rigidly held by trolley ears at intermediate points.

278. Terminations are made as shown in Fig. 208. Strain insulators separate the trolley wire electrically from the building members, and either a turnbuckle or an eyebolt with a long thread can be used for pulling the slack from the wire and adjusting its tension. The terminations should be depended upon to assume the entire tension of the wire. The intermediate supports are placed merely to prevent excessive sagging. The members which take the stresses of the eyebolts at the terminations should be very substantial, or thoroughly braced, because on them depends the reliability of the entire installation. The eyebolts, turnbuckles, and strain insulators should be not smaller than the $\frac{5}{8}$-in. size.

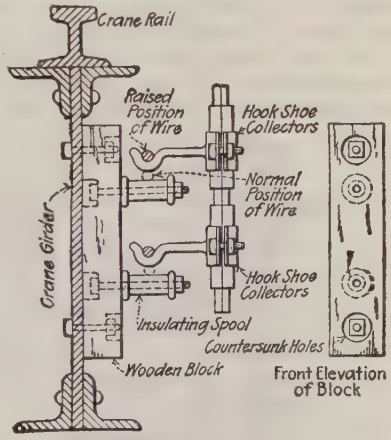


FIG. 207.—Intermediate bracket for trolley wire.

279. Intermediate supports for crane trolley wires, the supports installed between the terminations to prevent sagging, can be arranged as shown in Figs. 207, 209, and 210. The bracket of Fig. 207 is, as above outlined, applicable only where the crane has hook-shoe collectors. The block of wood that supports the insulating spools should be thoroughly dry and treated with an insulating paint. The bolt holes in it should be deeply countersunk, to eliminate the possibility of grounds. The spools should be of porcelain. Porcelain tubes with porcelain knobs

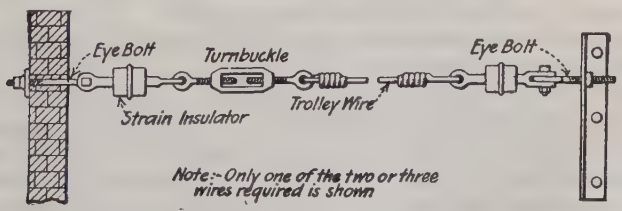


FIG. 208.—Trolley supports at ends of run.

at the ends to form flanges will do. The length of the insulator between flanges should be at least 4 in. Spools turned from fiber are sometimes used. The spools should be so arranged that there will be at least a $\frac{1}{2}$-in. clearance between them and the hook shoe when it passes along.

In a fireproof building, where the crane has trolley-wheel collectors, the wires can be supported by trolley ears as in Fig. 210. The wooden

supporting block must be thoroughly painted, and the bolt holes in it deeply countersunk, to prevent the possibility of grounds. Tap bolts, screwing in from the rear, support the screw-clamp trolley ears which seat against washers. Figure-eight or, preferably, grooved trolley wire is used. The wire should be drawn tightly at the terminations, and the ears should be installed every 8 or 10 ft.

For an outdoor crane, as well as for indoor applications, the wires can be supported in some cases as shown in Fig. 209. Standard street-railway-type trolley hangers and ears are used, which provide excellent

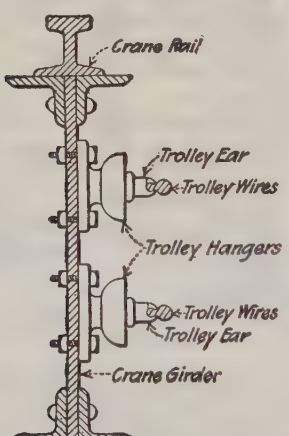


FIG. 209.—Trolley hanger support.

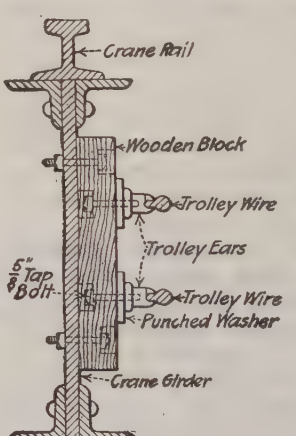


FIG. 210.—Trolly ear supports.

insulation. The hangers can, provided a proper location of the trolley wires results, be bolted directly to the crane girder.

280. There are almost numberless ways in which steel conductor rails can be arranged and supported. The arrangement of a structural-steel tee conductor or trolley rail is shown in Fig. 211. Although the arrangement illustrated was developed for serving monorail cranes, which travel on the lower flanges of I beams, only minor modifications in the supporting forging would be required to adapt it for serving bridge cranes or other similar traveling electrical machines. Note that a feature of the method is that no drilling or close fitting is required in the field. The only piece that is different for different jobs is the supporting forging, but this can be formed and drilled in the shop. The only tools required to erect the rail are a hack saw for cutting the tee, which is purchased in 30-ft. lengths, and a wrench for setting the bolts. No bolt smaller than $\frac{5}{8}$ in. diameter is used, because smaller ones than this can be twisted asunder too easily A $1\frac{1}{2}$- by $1\frac{1}{2}$- by $\frac{3}{16}$-in. T bar was selected,

because this is about the smallest size that is rigid enough to sustain itself effectively between supports. A T bar of this size has a con-

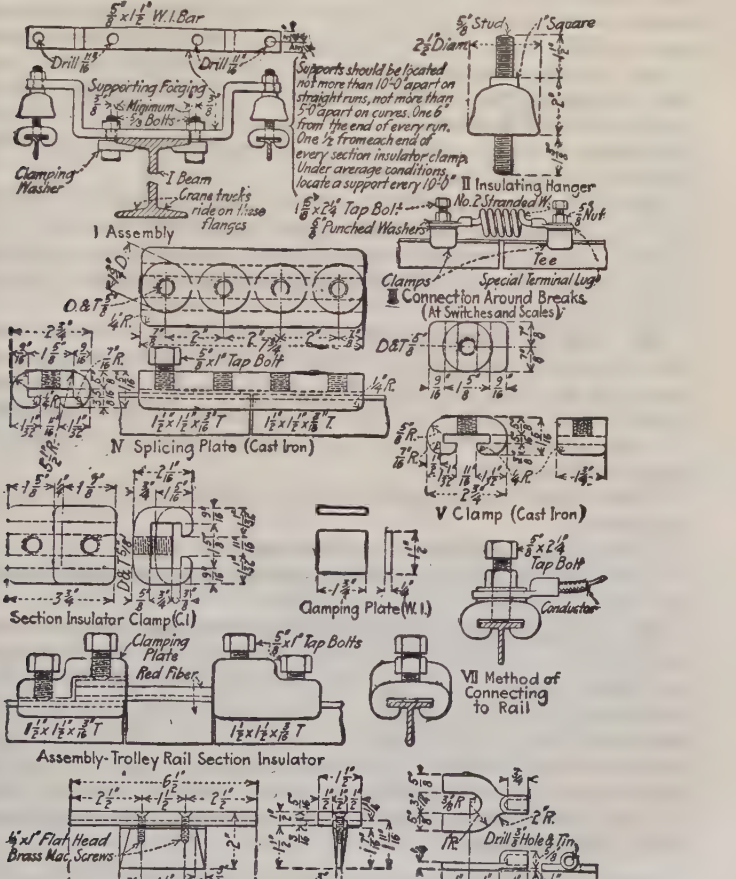


FIG. 211.—Steel trolley rail.

uctivity equivalent to that of a 109,800-cir. mil copper conductor, *i.e.*, copper conductor between Nos. 0 and 2/0 in size.

The insulating hanger (Fig. 211, II) is similar to a trolley hanger, ut smaller. A malleable-iron bell encloses the molded material that

supports and insulates the hanger stud. The Johns-Manville Co. makes the insulator to special order, and its mold number is 4689-B. The splicing plate (IV) and the clamp (V) are castings, preferably malleable iron, and the only machine work on them is the drilling and tapping of the holes. The section insulator (VI) consists of two castings, a fiber dividing block, and two wrought-iron clamping plates. Directions for spacing the insulating supports when erecting the conductor are given on the illustration. The terminal lug (VIII) is forked instead of annular, so that it can be readily disconnected for isolating circuits for testing without taking out a bolt.

Rigid collector conductors must have insulating supports spaced at intervals of not more than eighty times the vertical dimension of the conductor, but in no case greater than 15 ft., and spaced apart sufficiently to give a clear electrical separation of conductors or adjacent collectors of not less than 1 in.

281. Track as Circuit Conductor (National Electrical Code).—Monorail, tramrail, or crane-runway tracks may be used as a conductor of current for one phase of a three-phase a-c system furnishing power to the carrier, crane, or trolley, provided the following conditions are fulfilled:

1. The conductors for supplying the other two phases of the power supply shall be insulated.

2. The power for all phases shall be obtained from an insulating transformer.

3. The voltage shall not exceed 300 volts.

4. The rail serving as a conductor shall be effectively grounded at one point only, preferably at the transformer.

282. In computing the resistance of steel trolley rails, the area in square inches of the section involved can be taken from one of the steel companies' handbooks, such as are issued by the Cambria and Carnegie steel companies; the area in circular mils can then be obtained by using the rule given below. By dividing this area by 6.14, which is the approximate ratio of the resistance of mild steel to that of copper, the equivalent copper area of the steel conductor results. Then by using the standard formula for the resistance of a copper conductor, the actual resistance of the steel is obtained.

Example.—What is the resistance of 160 ft. of 1½- by 1½- by $\frac{3}{16}$-in. steel angle? (See Fig. 212 for a picture of the section.)

Solution.—By referring to a handbook, it will be noted that the area of 1½- by 1½- by $\frac{3}{16}$-in. steel angle is 0.53 sq. in. Then, to find its area in cir. mils,

$$\text{Cir. mils} = \frac{\text{area in sq. in.}}{0.000,000,785,4} = \frac{0.53}{0.000,000,785,4}$$
$$= 674{,}800 \text{ cir. mils.}$$

Then

$$\text{Equivalent in copper} = \frac{\text{cir. mils area of steel}}{6.14}$$
$$= \frac{674{,}800}{6.14} = 109{,}800 \text{ cir. mils}$$

Then the resistance of the 160-ft. length will be

$$\text{Resistance (for copper)} = \frac{11 \times \text{ft.}}{\text{cir. mils}} = \frac{11 \times 160}{109{,}800} = 0.016 \text{ ohm}$$

The resistance, therefore, of 160 ft. of 1½- by 1½- by 3/16-in. steel angle is 0.016 ohm. It is evident from the equivalent copper area of the steel (109,800 cir. mils), that the conductivity of the steel section will lie between the conductivities of No. 1/0 (105,500 cir. mils) and No. 2/0 (133,100 cir. mils) copper wire.

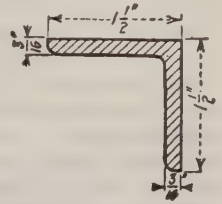


FIG. 212.—Section of 1½ in. × 1½ in. × 3/16 in. steel angle.

The equivalent copper area in circular mils can be used in any of the wiring formulas for computing drop in a steel conductor, just as the actual area of a copper conductor is used in the same formulas, and the result will be a correct one for the steel section. Obviously the above method is approximate, because the constants are approximate, but it is quite accurate enough for wiring computations, which always involve necessarily inaccurate assumptions.

283. Switch in Cab (National Electrical Code).—If cranes are operated from cabs, a motor circuit switch or circuit breaker shall be provided in the leads from the main collector conductors. The switch or circuit breaker shall be capable of interrupting the circuit under heavy loads and shall be capable of ready control by the operator.

On both a-c and d-c crane protective panels, the continuous ampere rating of the main-line switch or circuit breaker and main-line contactors shall be not less than 50 per cent of the combined short-time ampere ratings of the motors, nor less than 75 per cent of the short-time ampere rating of the motors required for any single crane motion.

284. Bridge collector conductors are required across the crane bridge for carrying the circuit to the carriage and hoist motors. They are usually made of bare copper wires supported in the same general way as described in Secs. **276** to **279** except that bridge collector conductors shall be kept at least 2½ in. apart, and, if the span exceeds 80 ft., insulating saddles shall be placed at intervals not exceeding 50 ft.

It is recommended that the distance between wires be greater than 2½ in. where practicable.

The wire must be large enough to carry the motor current as explained in Div. 3 and must not be smaller than given in the following table:

Distance between Rigid Supports, Ft.	Size of Wire
0–30	No. 6
31–60	No. 4
Over 60	No. 2

285. The motor-circuit wiring must be rubber or thermoplastic type, except that in dry locations it may be of varnished-cambric

type. Wiring exposed to severe external heat and wiring to resistors must be asbestos covered or may be slow burning if the temperature does not exceed 90°C. (194°F). The conductors must be of a size as given in Table 11 of Div. 11. Pilot circuits of controllers may be No. 16. The wiring must be enclosed in rigid metal conduit or electrical metallic tubing. Where flexible connections to motors or controllers are necessary, flexible metal conduit or armored cable may be used. In dry locations where space is limited, individual conductors may be separately encased in flexible tubing securely fastened in place. Short runs for control equipment in the cab or on the bridge may be enclosed in auxiliary gutters. Short lengths of conductors at resistors and collectors may be left open. A common-return conductor may be used for the several motors of a single crane or hoist.

286. Motor Control and Protective Equipment.—The hoist of cranes must be provided with a limit switch which will control the upper limit

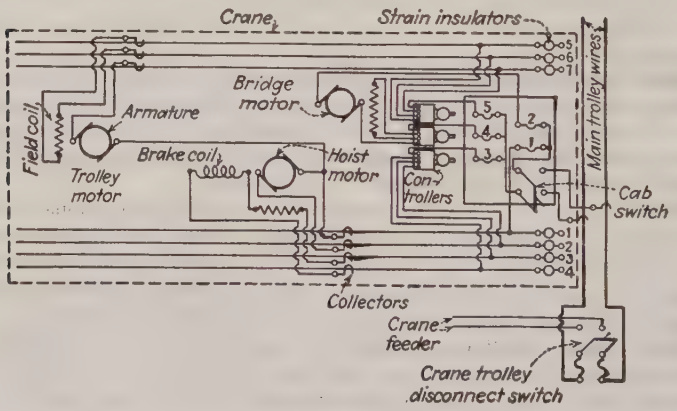


FIG. 213.—Direct-current crane wiring diagram.

of travel. It is best practice to arrange the control levers of all traveling cranes, in any one installation, in the same relative position in all the cages of the different cranes. The National Electrical Code allows two motors with their leads, which operate a single hoist, carriage, truck, or bridge and are controlled as a unit by one controller, to be protected by a single overload device. The device should be located in the cab if there is one.

287. A crane-wiring diagram is given in Fig. 213, which is typical for a d-c, three-motor, traveling bridge crane. Variations in crane wiring and control schemes are practically numberless. For d-c cranes, series motors are almost invariably used, while for a-c cranes, wound-rotor motors are used.

WIRING FOR CIRCUITS OVER 600 VOLTS

288. For wiring circuits operating at more than 600 volts, the conductors must have an insulation sufficient for the particular voltage employed. Open wiring may be used only in generator, transformer, switching, and motor rooms and in service runs. Open wires must have a flame-retardant outer covering and must be supported on insulators of a type approved for the purpose and must be at least 8 in. apart. For voltages between 600 and 2,500, the wires must be kept at least 2 in. from the surface wired over, and for voltages between 2,500 and 15,000, at least 3 in. Circuits of more than 15,000 volts may be used only for X-ray equipment or in transformer vaults, substations, and fire-resistive motor rooms, or the circuits may be run in conduit or duct enclosed in 2 in. of concrete, brick, or equivalent fire-resistive material. For locations other than those where open wiring is allowed, the wiring must be in rigid conduit, duct, or armored cable especially approved for the voltage. Lead-covered cables must be terminated in potheads. All live parts including conductors must be enclosed or isolated if accessible to unqualified persons. Isolation may be accomplished by elevation of the live parts to a height as given by the following table:

Voltage between phases	Minimum vertical clearance of unguarded parts from floor or working surface	Voltage between phases	Minimum vertical clearance of unguarded parts from floor or working surface
600–6,600	8 ft. 0 in.	66,000	10 ft. 5 in.
11,000	9 ft. 0 in.	88,000	11 ft. 0 in.
22,000	9 ft. 3 in.	110,000	11 ft. 7 in.
33,000	9 ft. 6 in.	132,000	12 ft. 2 in.
44,000	9 ft. 10 in.		

289. Switches, circuit breakers, and control apparatus on circuits exceeding 5,000 volts between conductors (National Electrical Code) shall have a metal enclosure such as metal-clad switchgear, trucks, and cubicles, or be installed remotely controlled in a fire-resistive switch room or motor room or in a vault.

If live parts of equipment in such metal enclosures carry more than 600 volts and are accessible by means of a door, the door shall be provided with a lock, so that it cannot be opened by unauthorized persons, or shall be provided with an interlock which will prevent opening unless the parts thereby exposed are de-energized.

If connected to a circuit exceeding 15,000 volts between conductors, such apparatus shall be installed only in a vault.

Oil circuit breakers and oil switches are to be isolated. Oil circuit breakers and oil switches shall be solated from other apparatus wherever practicable. If mounted in a closed compartment, means shall be provided to indicate whether the breaker is open or closed.

It is recommended that oil switches used to control transformers be outside the vaults containing the transformers.

Switches are to be safely accessible. All switches shall be so located that the point from which they are operated is safely accessible to qualified and authorized persons. Isolating switches shall be accessible to qualified persons only. Barriers should be provided on both sides of isolating switches.

Warning Signs.—Unless isolating switches are so interlocked that they cannot be opened under load, signs shall be installed at isolating switches warning against opening them while they are carrying current.

290. Overcurrent Protection (National Electrical Code).—Each transformer, or bank of transformers operating as a unit, except instrument transformers, and each other operating unit of apparatus, shall be protected from overcurrent by a manually or power operated circuit breaker which will interrupt all ungrounded conductors, except that fuses may be used as given in Sec. **291.**

291. Oil-filled or other suitable types of fuses may be used on circuits not exceeding 15,000 volts for the following purposes:

1. For the protection of individual feeder or branch circuits at the point where they receive their supply. If there is more than one such circuit, there shall be a manually operable circuit breaker between the point of origin of such circuits and the source of supply.

2. For the protection of individual transformers, or banks of transformers operating as a unit when such transformers are supplied by a common feeder, provided that such feeder at the point where it receives its supply shall be protected by a circuit breaker which can be operated manually by either mechanical or electrical means. A circuit supplying a single transformer or bank of transformers need not have circuit-breaker protection.

3. For the protection of motors.

4. For the protection of other classes of apparatus by special permission.

Fusible cutouts shall be so installed that the blowing of the fuse will not result in injury to persons or damage to other equipment. They shall be accessible to qualified attendants only.

WIRING FOR CIRCUITS LESS THAN 50 VOLTS

292. For wiring circuits of less than 50 volts, conductors not smaller than No. 12 must be used. If the conductors supply more than one appliance or appliance receptacle, they must not be smaller than No. 10. Not more than 8 lamp holders or receptacles or a total load of more than

320 watts may be connected to a branch circuit. Motors or appliances rated at more than 320 watts must have individual branch circuits. Receptacles must be rated at not less than 15 amp.; in kitchens, laundries, and other locations where portable appliances are likely to be used the receptacles must be rated at not less than 20 amp.

WIRING FOR HAZARDOUS LOCATIONS

293. Hazardous locations are divided by the National Electrical Code into three classes. Each of these is further subdivided into Divs. 1 and 2. In Div. 1 the hazardous material is more or less freely present in the air in connection with manufacture. In Div. 2 the hazardous material is confined in containers; and explosive mixtures with air will occur only in case of accident or through failure of ventilating systems to operate properly.

Class I.—Locations in which highly inflammable gases or liquids are manufactured, used, stored, or handled, such as hydrogen, gasoline, alcohol, etc.

Class II.—Locations in which combustible dust is likely to be thrown into suspension in the air in sufficient quantities to produce explosive mixtures, such as flour mills, grain elevators, coal pulverizing plants, etc.

Class III.—Locations in which easily ignitible fibers or materials producing combustible flyings are handled or used or stored, such as textile mills, cotton gins, or woodworking plants.

294. Equipment for installation in hazardous locations Classes I and II must be tested and approved for use, according to the following classification of the hazard involved.

Class I, Group A, atmospheres containing acetylene.

Class I, Group B, atmospheres containing hydrogen or gases or vapors of equivalent hazard, such as manufactured gas.

Class I, Group C, atmospheres containing ethyl ether vapor,

Class I, Group D, atmospheres containing gasoline, petroleum, naphtha, alcohols, acetone, lacquer-solvent vapors, and natural gas.

Class II, Group E, atmospheres containing metal dust.

Class II, Group F, atmospheres containing carbon black or coal or coke dust.

Class II, Group G, atmospheres containing grain dust.

295. In Class I, Div. 1 hazardous locations all wiring must be in rigid metal conduit with explosionproof fittings. Division 2 locations may use electrical metallic tubing with flexible metal conduit where necessary, as at motor terminals. All equipment such as circuit breakers, fuses, motors generators, and controllers must be totally enclosed in explosion-proof housings.

296. In Class II, Div. 1 hazardous locations the wiring must be in rigid conduit or flexible metal conduit or type *S* cord where necessary, as

at motor terminals, and must have threaded fittings. All equipment must be in dustproof cabinets with motors and generators in totally enclosed fan-cooled housings. In Div. 2 locations electrical metallic tubing may also be used.

297. In Class III, Div. 1 hazardous locations the wiring must be of the same type as in Class I. In Div. 2 locations open wiring is permitted, provided the conductors are protected where they are not run in roof spaces or well out of reach of mechanical injury. If the atmosphere is such that lint and flyings will collect on motors or generators they must be enclosed as in Class II. For further special rules for hazardous locations in regard to receptacles, plugs, lighting fixtures, portable cords, cranes, control equipment, service equipment, panel boards, etc., consult the National Electrical Code.

INSTALLATION OF APPLIANCES

298. Connection to Circuit and Protection.—A portable appliance may be connected only to a receptacle having a rating at least as great as the appliance (see Table 376).

The standard duplex convenience outlet receptacle is rated at 15 amp. and may supply a single 15-amp. fixed appliance or a 12-amp portable appliance if used on a 15-amp. branch circuit. Heavy-duty receptacles rated at 20, 30, and 50 amp. may be obtained for higher current appliances. These must be used with branch circuits of the same rating except that 20-amp. receptacles may also be used on 30-amp. branch circuits. These may be two wire, two wire polarized (for direct current), and three wire polarized. Refer to Div. 4 for description of receptacles. Most household appliances, such as toasters, hot plates, percolators, flat irons, waffle irons, refrigerators, radiant heaters, roasters, portable ovens, etc., are rated at less than 12 amp. so that they may be used in the standard outlet on a 15-amp. circuit. Some of the roasters and ovens are rated at 15 amp. so that they require a 20-amp. branch circuit.

Appliances other than motor-operated ones are not required to have individual overload protection. They are considered to be satisfactorily protected by the overload protective devices in the branch circuit to which they are connected. The protection of motor-operated appliances must be in accordance with the rules given in Sec. **432** of Div. **7**.

299. In wiring appliances one of the approved types of cords listed in Div. 2 should be used. If the appliance is rated at more than 50 watts and temperatures of more than 121°C. (250°F.) are produced on surfaces with which the cord is apt to be in contact, one of the types of heater cords must be used. Every heating appliance which is intended to be applied to combustible material, as a smoothing iron, must be equipped with a stand, which may be separate or a part of the appliance. Each heating appliance intended to be located in a fixed position must have

ample protection provided between the appliance and adjacent combustible material.

300. Disconnecting Means (National Electrical Code).—Each appliance shall be provided with a disconnecting means, which may be a switch, a separable connector, or a plug receptacle, and shall conform to the following:

1. It shall be readily accessible to the operator of the appliance.

2. In other than dwelling occupancies the branch-circuit switch or circuit breaker, if readily accessible to the user of the appliance may be used.

3. In multifamily (more than two) dwellings the switch shall be within the apartment, or on the same floor as the apartment in which the appliance is installed, and may control lamps and other appliances.

4. In two-family dwellings the switch may be outside the apartment in which the appliance is installed. This will permit an individual switch for the apartment to be used.

5. In single-family dwellings the service switch may be used.

Unit Switches.—Switches controlling the individual units of appliances shall not be considered as taking the place of the single disconnecting means.

301. Switch to Be Indicating.—If a switch is used as the disconnecting means it shall be of the indicating type.

302. Portable appliances need not be grounded unless they operate at a voltage of more than 150 to ground.

303. Signals and Temperature-limiting Devices for Heated Appliances. In other than residence occupancies, each electrically heated appliance or group of electrically heated appliances intended to be applied to combustible material shall be installed in connection with a signal unless the appliance is provided with an integral temperature-limiting device.

304. The electric range consists of a number of heater elements each rated at 1,000, 1,200, 1,500, or 2,000 watts, so that it must usually be supplied with an individual three-wire branch circuit. The heater elements usually contain two units controlled by connecting the units in various combinations of series and parallel between the two lines and the neutral. Some types also provide a rheostatic control for gradual adjustment for simmering on low heat.

305. Building Heating.—With the usual electric rates available, heating buildings electrically is ordinarily too expensive to be practical. But, for small buildings or for buildings located where the climate is mild, electric heating may be more practical and cheaper than any other type. Electric heaters are frequently used for heating small areas of large industrial plants. A very approximate rule to determine the amount of power required is to allow 1 watt per cu. ft. of air space for a temperature difference between outside and inside of 40°F., or find watts per sq. ft. from Fig. 214, according to the temperature difference expected

between inside and outside the wall. Then total up the watts required for the different walls and add an allowance for heating up fresh air (0.11 watt per cu. ft. will allow for three changes of air per hour with a 70° temperature difference; any other values will be proportional). Electric heating is practically 100 per cent efficient since all the power is turned into heat, and the only loss is that required to raise the temperature of the material of the heater initially to the operating temperature.

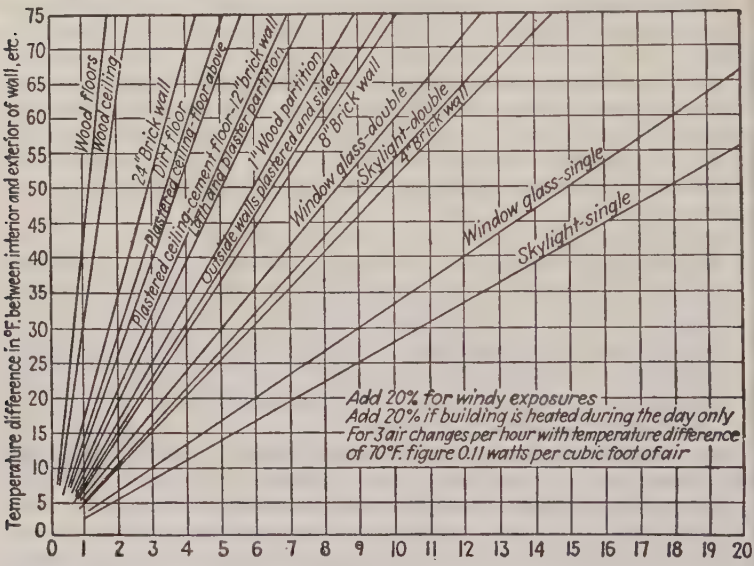


FIG. 214.—Heat losses through walls, etc., measured in watts per square foot of surface.

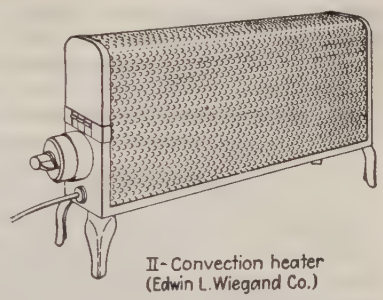
306. Heaters as used in buildings are of three general types: 1. Radiant heaters (Fig. 215, I) which have a coil heating element in the center of a curved surface of copper or chromium plate. These heaters do not heat the air appreciably but throw off radiant heat rays which warm any opaque object in their path. They are primarily useful for warming one's body in the bathroom or in time of illness.

2. Convection heaters (Fig. 215, II) heat the air, which in turn rises and circulates all over the room. To be effective they should be located a few inches off the floor and have an unobstructed path for the circulation of air through them. They are available in sizes up to about 5 kw.

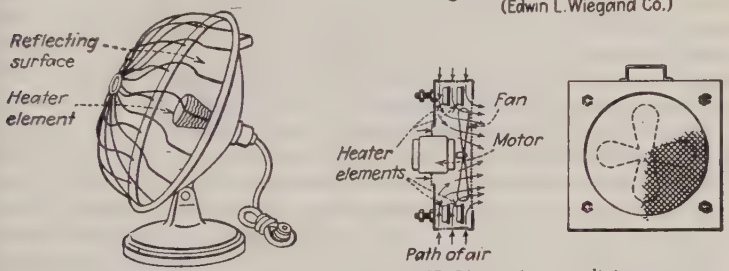
3. Blower-type unit heaters (Fig. 215, III) have a fan which forces the air over the heater elements and out into the room. This type of heater is usually located high up on the wall so as not to produce too much draft. It has the advantage of rapid circulation of air and is useful in

hard-to-heat corners and for temporary heating at a rapid even rate. They are available in sizes up to 40 kw.

307. Electric water heaters for domestic use make use of either immersion heaters or strip heaters. The immersion heaters (Fig. 216, I) have the heating coil embedded in refractory material inside a cartridge sheathed with copper. It is inserted in the side of a tank with



II - Convection heater (Edwin L. Wiegand Co.)

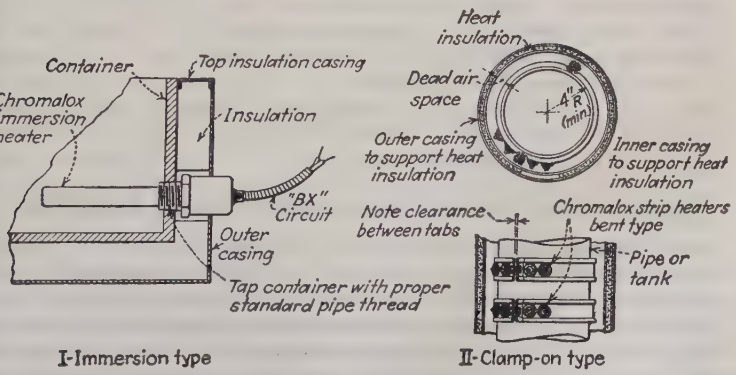


I - Radiant heater (General Electric Co.)

III - Blower type unit blower (Edwin L. Wiegand Co.)

FIG. 215.—Room heaters.

the terminals projecting on the outside. This is the type generally used for tanks orginally designed as electric water heaters. For converting an



I-Immersion type

II-Clamp-on type

FIG. 216.—Water-heater elements.

existing hot-water boiler for electric water heating, curved strip heaters (Fig. 216, II) are clamped around the outside of the tank. In either

case a heavy corrugated asbestos insulating covering should completely cover the tank to minimize heat loss. There should be a dead-air space between the insulation and the strip heaters to prevent highly localized heating of the strips, which would occur if the insulation were placed against the heater.

308. Many power companies have an "off-peak," water-heating rate in which they charge from ¾ to 1½ cts. per kw.-hr. for power used by the water heater during the night. This is registered on a separate meter, and the circuit may be controlled by a time-clock switch or by carrier-current relaying. The latter method is preferable from the standpoint of the customer because the low rate may be obtainable any time that the system maximum demand is low enough to warrant switching on the water-heating circuits. Such a metering system usually requires two water heating units, one of small capacity (about 750 or 1,000 watts) located low in the tank and operated from the off-peak circuit to keep the entire tank at as high a temperature as possible. The other unit is of larger rating (1,500 or 2,000 watts) located near the top of the tank to act as a booster to heat the water in the top of the tank rapidly at times when the other unit does not keep the water hot enough. Either or both units may be equipped with thermostatic or manual control. Other companies have a step rate in which the power used by the water heater is supposed to fall in the lowest step blocks. This has the advantage of simpler metering and control but allows the water-heating load to determine the system maximum demand. If the rate is set low enough to be attractive to prospective customers, it may be uneconomical for the power company. Unless the customer has an electric range the power used by the water heater will usually fall in too high a rate step to be attractive to him. Considerable experimentation is still being tried with different rates to determine the proper metering to give satisfaction to both the customer and the power company. Apparently some method of preventing the water-heating load from adding to the system peak and at the same time filling in the valleys of the system load curve, when generating and distribution facilities are partially idle, is the most satisfactory to all concerned.

WIRING FOR ELECTRIC SIGN AND OUTLINE LIGHTING

309. Types of Signs.—Electric signs or outline lighting may consist of incandescent lamps or gaseous-discharge tubing (commonly called neon signs). Refer to Div. 10 for discussion of lamps and tubing.

310. Methods of Wiring Incandescent Electric Signs (Data on Electric Signs, The National Electric Light Association).—Lamps burning in multiple may be connected either two wire or three wire, as shown in Fig. 217. In series wiring, lamps may be connected either in straight series or multiple series, as shown. Where transformers (see division on Transformers for information on sign transformers) are used to obtain

low voltage, lamps may be connected either two wire or three wire as in standard multiple wiring, the transformer reducing the voltage from the regular 110- or 220-volt circuits to the voltage required by the lamp. The ordinary multiple wiring can be changed to straight series wiring by merely clipping the alternate connections between lamps (Fig. 218).

In a large sign any combination of series or multiple series may be used. With straight series wiring, should one lamp in the series burn out, all

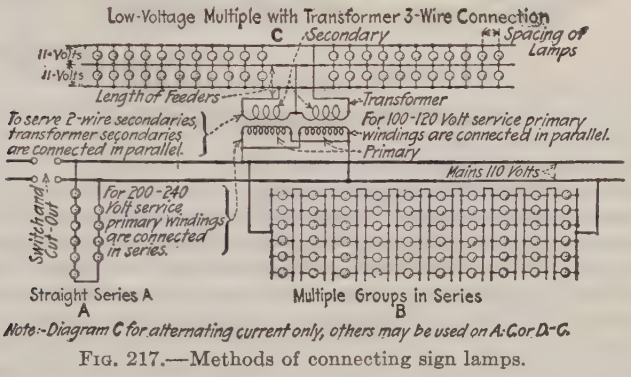


Fig. 217.—Methods of connecting sign lamps.

the lamps in that series will be out. If the lamps are connected in multiple series, the failure of one lamp does not cause any of the other lamps to go out. However, there should not be less than eight to ten lamps in each multiple group, or the failure of one lamp will cause too much current to flow through the other lamps of the same group, thus shortening their lives.

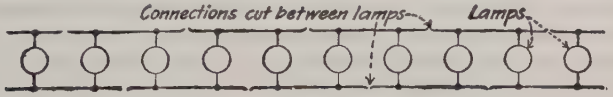


Fig. 218.—Method of changing sign wiring from multiple to series.

311. Different effects of flashing or motion may be obtained with incandescent signs by the use of a sign flasher. Cams or a drum are mounted on a shaft that is rotated by a small electric motor (Fig. 219). The circumferences of the cams or of the drums are so cut that, in the brush-type flashers, the brushes will make contact only during certain predetermined portions of a revolution and thereby complete the electric circuit through the sign lamps only during that period. In the carbon-type flashers the cams, instead of carrying current and making and breaking the contacts directly, operate to open and close carbon-break contact switches which control the sign lamps. The possible variations in arrangement of cams and drums for producing different effects are almost numberless.

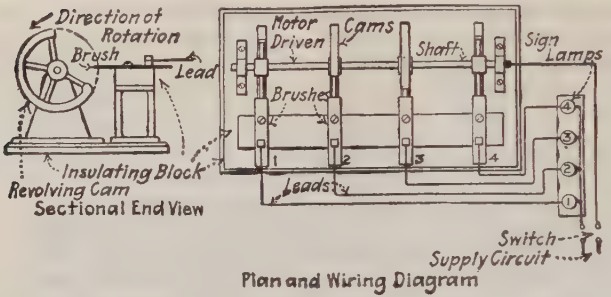


FIG. 219.—The elementary sign flasher.

312. Method of Wiring Neon-lamp Signs.—Neon lamps used for signs are of the high-voltage type (see Div. 10). The lamps are supplied from ordinary lighting circuits through small step-up transformers. The voltage required depends upon the length of neon-lamp tubing used in the sign. The maximum voltage employed on the lamps is 15,000. When the length of tubing is greater than can be illuminated with 15,000 volts, two or more transformers are employed as required. Practically always neon signs are completely wired and installed by the manufacturers, the purchaser simply providing the necessary outlets from the general lighting system. Also, the servicing and maintenance of the signs generally is handled by the manufacturer.

313. The installation of all signs or outline lighting, whether of the incandescent or gaseous-discharge type, must meet the following requirements: All equipment and devices used with signs must be enclosed in metal boxes. Except for portable incandescent signs, the boxes must be grounded, unless they are insulated from ground and other conducting surfaces and are inaccessible to unauthorized persons. Each sign, except a portable one, must be controlled by an enclosed, externally operable switch located within sight of the sign or, if not so located, capable of being locked in the open position. All devices, such as switches, flashers, etc., unless of a specific type approved for this type of application must have a current rating which is not less than twice the current rating of the transformer supplying the sign. The circuits must be so arranged that none will have a load of more than 15 amp.

314. The installation of signs (600 volts or less) must be in accordance with the following National Electrical Code requirements. Additional explanatory notes are printed in italics.

Conductors shall be installed as follows:

a. Method of Wiring.—Conductors shall be installed as open conductors on insulators, or in rigid metal conduit, flexible metal conduit, electrical metallic tubing, armored cable, or metal troughing.

b. Insulation and Size.—Conductors shall be not smaller than No. 14, and of a type approved for the purpose and voltage of the circuit.

c. Lead-covered Conductors.—Conductors in rigid conduit, electrical metallic tubing, flexible metal conduit, armored cable, or in metal troughing exposed to the weather, shall be of the lead-covered or of specially approved type except where rigid conduit, electrical metallic tubing, or enclosures are made raintight and arranged to drain.

d. Number of Conductors in Raceway.—For sign flashers the number of conductors in conduit or tubing may be in accordance with Table 23 of Div. 11.

e. Open Conductors.—Open conductors on insulators shall comply with the provisions of *the Code as given in Secs.* **26** *to* **53** and, if outdoors, *with the requirements given in Div.* 8, except that the separation between conductors need be only 2 in., provided that open conductors may be supported by lamp holders located not more than 1 ft. apart.

f. Conductors Soldered to Terminals.—Where the conductors are fastened to lamp holders other than of the pin type, they shall be soldered to the terminals, and the exposed parts of conductors and terminals shall be treated to prevent corrosion. Where the conductors are fastened to pin type lamp holders which protect the terminals from the entrance of water, and which have been found acceptable for sign use, the conductors shall be of the stranded type but need not be soldered to the terminals.

Lamp Holders.—Lamp holders shall be of the unswitched type with bodies made of suitable insulating material and shall be so constructed and installed as to prevent turning. Miniature lamp holders shall not be employed for outdoor signs and outline lighting.

315. The installation of gaseous-discharge signs (exceeding 600 volts) must be in accordance with the following National Electrical Code requirements (Secs. **316** to **320**):

316. Transformers.—Transformers shall be of approved type and be accessible. They shall be limited to 4,500 volt-amperes and have a secondary open-circuit voltage of not over 15,000 volts with an allowance on test of 1,000 volts additional. The high-voltage terminals shall be inaccessible to unqualified persons. Open-core and coil-type transformers shall not be used except in the small portable indoor type of signs limited to 5,000 volts with an allowance on test of 500 volts additional. In end-grounded transformers, the secondary open-circuit voltage shall not exceed 7,500 volts with an allowance on test of 500 volts additional. Transformers for outline lighting installations shall have secondary-current ratings not in excess of 30 milliamperes, unless they and all wiring connected to them are installed in accordance with the provisions for electric discharge lighting of the same voltage.

Transformer Secondary Connections.—The high-voltage windings of

transformers shall not be connected in parallel and shall not be connected in series, except that two transformers, each having one end of its high-voltage winding connected to the metal enclosure, may have their high-voltage windings connected in series to form the equivalent of a mid-point grounded transformer. The grounded ends shall be connected by insulated conductors not smaller than No. 14.

317. Installation of Conductors.—Conductors shall be installed as follows:

a. Wiring Method.—Conductors shall be installed as open work, as concealed conductors on insulators, or in rigid or flexible metal conduit or electrical metallic tubing. Conductors may be run from the ends of tubing to the grounded mid-point of transformers specifically designed for the purpose and provided with terminals at the mid-point. Where such connections are made to the transformer-grounded mid-point, the connections between the high-voltage terminals of the transformer and the line ends of the tubing shall be as short as possible.

b. Insulation and Size.—Conductors shall be of a type approved for the purpose and for the voltage of the circuit, and shall not be smaller than No. 14.

c. Bends in Conductors.—Sharp bends in the conductors shall be avoided.

d. Open Conductors—Indoors.—Open conductors indoors shall be mounted on noncombustible, nonabsorptive insulators. Insulators of porcelain shall be glazed on all exposed surfaces. A separation of at least 1½ in. shall be maintained between conductors and between conductors and other objects. Conductors shall not be located where subject to mechanical injury.

e. Concealed Conductors on Insulators—Indoors.—Concealed conductors on insulators shall be separated at least 1 in. for voltages up to 10,000 and 1½ in. for voltages over 10,000 volts from each other and from all objects other than the insulators on which mounted. They shall be installed in channels lined with noncombustible material and used for no other purpose, except that the primary-circuit conductors may be in the same channel. The insulators shall be of noncombustible, nonabsorptive material.

f. Show Windows and Similar Locations.—If conductors hang freely in the air, away from combustible material, and if not subject to mechanical injury, as in some show-window displays, they need not be otherwise protected.

g. Conductors in Raceways.—If the conductors are covered with lead or other metal sheathing, the covering shall extend beyond the end of the raceway, and the surface of the cable shall not be injured where the covering terminates. In damp or wet locations, the insulation on all conductors shall extend beyond the metal covering or raceway at least 4 in. for voltages over 10,000, 3 in. for voltages over 5,000 but not exceeding

10,000, and 2 in. for voltages of 5,000 or less. In dry locations, the insulation shall extend beyond the end of the metal covering or raceways not less than 2½ in. for voltages over 10,000, 2 in. for voltages over 5,000 but not exceeding 10,000, and 1½ in. for voltages of 5,000 or less. For conductors at grounded mid-point terminals, no spacing is required. Not more than 20 ft. of cable from a single transformer shall be run in metal raceway where the potential between the cable and the raceway is more than 5,000 volts.

h. Open Conductors—Outdoors.—Open conductors outdoors shall be mounted on noncombustible, nonabsorptive insulators. Insulators of porcelain shall be glazed on all exposed surfaces. A separation of at least 2 in. shall be maintained between conductors and between conductors and other objects. Where subject to mechanical injury, or where within reach from ground, roof, or window, conductors shall be enclosed in raceways or suitably guarded. If guarded, a spacing of not less than 1½ in. shall be maintained between conductors and the enclosure unless the enclosure is nonconducting and noncombustible.

318. Tubing.—The tubing shall be free from contact with flammable material and shall not be located where normally exposed to mechanical injury. It shall be supported on noncombustible, nonabsorptive insulating supports and when operating in excess of 7,500 volts shall be kept at least ¼ in. from the nearest surface. The tubing shall be of such length and design as not to cause a continuous overvoltage on the transformer.

319. Terminals and receptacles for electric discharge tubing shall comply with the following:

a. Terminals.—The terminals of the tubing shall be inaccessible to unqualified persons and isolated from combustible material and grounded metal or shall be enclosed. If enclosed, they shall be separated from grounded metal and combustible material by nonabsorptive, noncombustible insulating material approved for the purpose, or by 1½ in. of air. Terminals shall be relieved from stress by the independent support of the tubing.

b. Tube Connections Other than with Receptacles.—If tubes do not terminate in receptacles designed for the purpose, all live parts of tube terminals and conductors shall be so supported as to maintain a separation of at least 1½ in. between conductors or between conductors and any grounded metal.

c. Receptacles.—Electrode receptacles for gas tubing shall be of noncombustible, nonabsorptive insulating material approved for the purpose.

320. Enclosures.—Enclosures for signs and outline lighting shall conform to the following:

a. Conductors and Terminals.—Sign boxes, cabinets, and outline troughs shall have conductors and terminals, except the supply leads, enclosed.

b. Cutouts, Flashers, Etc.—Cutouts, flashers, and similar devices shall be enclosed in metal boxes, the doors of which shall be arranged so

that they can be opened without removing obstructions or finished parts of the enclosure.

c. Enclosures Exposed to Weather.—Enclosures for outside use shall be weatherproof and shall have an ample number of drain holes, each not larger than ½ or smaller than ¼ in.

d. Material.—Except for portable signs of the indoor type, signs and outline lighting shall be constructed of metal or other noncombustible material. Wood may be used for external decoration if placed at least 2 in. from the nearest lamp holder or current-carrying part.

e. Strength.—Enclosures shall have ample strength and rigidity.

f. Thickness of Metal.—Sheet copper shall be at least 20 oz. (0.028 in.). Sheet steel may be of No. 28 U.S. Standard gage (0.0149 in.) except that for outline lighting and for electric discharge signs sheet steel shall be of No. 24 U.S. Standard gage (0.0239 in.), unless ribbed, corrugated, or embossed over its entire surface, when it may be of No. 26 U.S. Standard gage (0.0179 in.).

g. Protection of Metal.—All metallic parts of enclosures shall be galvanized or otherwise protected from corrosion.

h. Switches on Doors.—Doors or covers giving access to uninsulated parts of indoor signs or outline lighting exceeding 600 volts and accessible to the general public shall be either provided with interlock switches which on the opening of the doors or covers disconnect the primary circuit, or so fastened that the use of other than ordinary tools will be necessary to open them.

321. Current-carrying Capacities of Flashers.—Double-pole flashers are made in four sizes that will carry respectively 15, 30, 45, or 60 amp. per switch. Single-pole carbon flashers are made that will carry 5 amp. per switch. Brush-type flashers are rated at from 2 to 5 amp. on each brush and are not reliable for greater currents. Noncarbon, double-pole-switch flashers are made for currents of 15 amp. and greater, but it is claimed by some manufacturers that 15 amp. should be the maximum because no knife switch can successfully break greater currents continuously.

322. Wiring and Installing Brush-type Flasher.—Figure 220 shows the wiring for a sign for "spelling" out. The neutral wire (or one main on a two-wire system) runs direct to the sign through the customary cutouts, and the outside "legs" (or remaining main on a two-wire system) run to the flasher as a common feed. From the flasher one wire is run to each individual letter through the customary cutouts. In the case of a double-face sign, two like letters can be connected in multiple and regarded as one circuit, provided the load which one switch of the flasher is designed to carry is not exceeded.

Always install so that the copper brushes are at the front of the flasher. Follow the general installation directions given for carbon flashers in another paragraph.

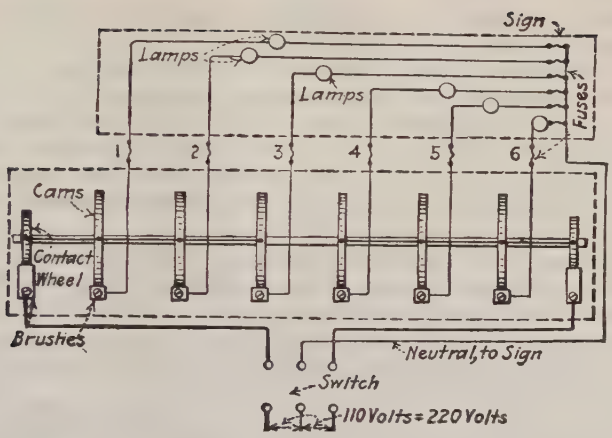


FIG. 220.—Wiring of three-wire brush-type flasher.

323. Wiring diagrams for carbon sign flashers (Reynolds Dull Flasher Co., Chicago) are given in Fig. 221. Unless otherwise ordered, flashers are furnished requiring a wiring arrangement like that at III. The load is balanced by running the neutral around the machine to the cutouts, breaking only the outside legs on a 220/110-volt system.

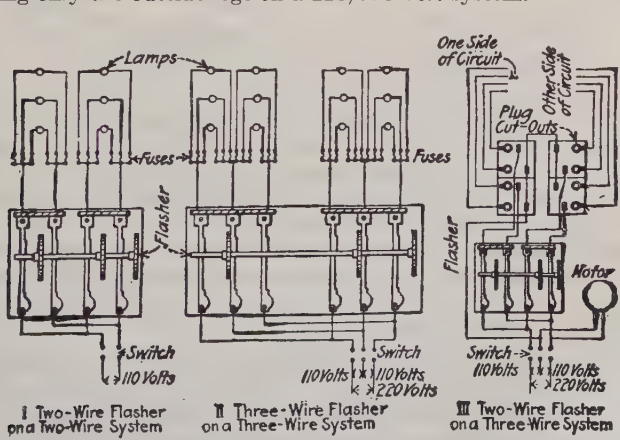


FIG. 221.—Wiring diagrams for carbon sign flashers.

324. In installing and wiring a carbon flasher (Reynolds Dull Flasher Co., Chicago) run the mains to the upper bridge of the flasher, and run the submains to the sign and to the terminals on the base of the machine. The submains are divided into the small circuits either in the sign or as

close thereto as possible to save the cost of wiring. The maximum load on a branch circuit must not exceed 15 amp.

Place the flasher on a shelf, in such manner that the carbons are in the front, the motor at the left with the commutator side to the front.

Do not screw either flasher or motor down tight but leave ⅛ in. clearance under the heads of the screws. The top of a show window, a board partition, or anything that acts as a sounding board will increase the noise threefold, and, when it is necessary to install in such places, arrange an extra set of rubbers under the shelf also.

325. Wiring for the so-called "high-speed" effects (Reynolds Dull Flasher Co., Chicago) such as running fountains, rising smoke, flames, traveling borders, and revolving wheels are wired as indicated in Fig. 222. The diagram at I is for the effect where the sign lamps are in a single line, and the same general arrangement is used for a traveling border. For a

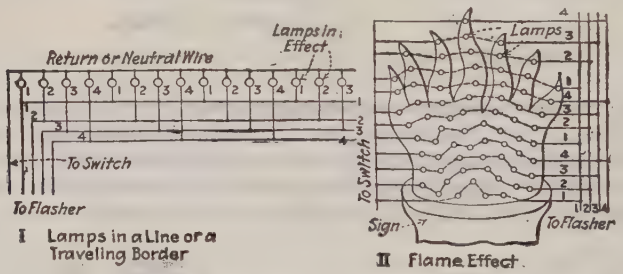


FIG. 222.—Wiring of "high-speed" effect signs.

fountain effect, number the lamps at the beginning of each stream and so continue to the end of the stream, and where several streams run parallel all the lamps in one horizontal row can be connected to the same branch as though they were one lamp. Traveling borders on an ordinary 3- by 10-ft. sign should have lamps spaced about 6 in. apart. In a fountain 15 ft. high the lamps should be about 9 in. apart. Figure 222, II, shows the wiring diagram for smoke, flame, steam, dust, and running-water effects. Avoid a straight-across arrangement of lamps, as the resulting effect will be unnatural.

326. The wiring for a flashing illuminated sign, *i.e.*, a painted sign which is successively illuminated (by lamps carried in a reflector trough above it) and darkened by the lamps being extinguished is shown in Fig. 223. Lamps should be mounted not more than 12 in. apart in the reflector, which should preferably be of the silver-backed type. For flashing in colors, but three can be used, namely, red, clear, and amber. Other colors such as green, blue, etc., are too dense to produce a good effect, and little light will throw down more than 8 ft. A carbon-type flasher should be used.

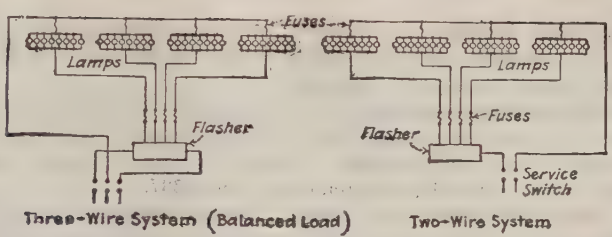


FIG. 223.—Wiring for flashing sign.

SIGNAL WIRING—LOW ENERGY POWER AND COMMUNICATION WIRING

327. Signal wiring systems are used for protective purposes such as fire-alarm, burglar-alarm, remote control, and similar systems and circuits operated as a part of a central-station system such as telephone, telegraph, and district messenger. They are divided by the National Electrical Code into two classes as follows:

a. Class 1.—Systems in which power is not limited.

Systems of Class 1 are subject to the regular National Electrical Code wiring rules.

For detailed service provisions for Fire Alarm Sprinkler, Supervisory, or Watchman systems, see standards of the National Board of Fire Underwriters.

b. Class 2.—Systems in which the power is limited:

(1) **Maximum 15 Volts; 5 Amp.**—Circuits operating at not exceeding 15 volts and fused at not more than 5 amp. If the current supply is from transformers or other devices having inherent current-limiting characteristics and approved for the purpose, or from primary batteries, the fuse may be omitted.

(2) **15 to 30 Volts; 3 Amp.**—Circuits operating at more than 15 volts, but not exceeding 30 volts, and fused at not more than 3 amp. If the current supply is from transformers or other devices having inherent current-limiting characteristics and approved for the purpose, or from primary batteries, the fuse may be omitted.

(3) **30 to 60 Volts; 1⅓ Amp.**—Circuits operating at more than 30 volts, but not exceeding 60 volts, and fused at not more than 1⅓ amp. If the current supply is from a transformer or other device having inherent current-limiting characteristics and approved for the purpose, the fuse may be omitted.

(4) **60 to 150 Volts; 1 Amp.**—Circuits operating at more than 60 but not over 150 volts and fused at not more than 1 amp., provided that such circuits are equipped with current-limiting means other than fuses which will limit the current as a result of a fault to not exceeding 1 amp.

Transformer Rating.—Transforming devices supplying local circuits covered in paragraph *b* of this section shall be restricted in their rated output to not exceeding 100 volt-amp.

328. Wiring Requirements.—The National Electrical Code requires systems of Classes 1 or 2 to be installed in accordance with the regulations given in Secs. **329** to **336.** Wiring for Class 1 systems must in addition comply with the requirements of Sec. **337.**

329, Protective Devices for Central Station Systems.—A protector approved for the purpose shall be provided on each circuit, aerial or underground, so located within the block containing the building served as not to be liable to accidental contact with light or power conductors operating at a potential exceeding 300 volts, and on each circuit run partly or entirely in aerial wire or cable not confined within a block.

The word "block" shall be construed to mean a square or portion of a city, town, or village enclosed by streets and including the alleys so enclosed but not any street.

a. Location.—The protector shall be located in or on the building as near as practicable to the point where the conductors enter. In the case of an underground entrance the protector may be located at the junction of the underground and the aerial wires.

b. Hazardous Locations.—The protector shall not be located in any hazardous location (see Sec. **293**), nor in the vicinity of easily ignitible material.

c. Protector Requirements.—The protector shall be mounted on a noncombustible, nonabsorptive insulating base and shall consist of an arrester between each line conductor and the ground, and a fuse in each line conductor, the fuses protecting the arrester. The protector terminals shall be plainly marked to indicate line, instrument, and ground.

d. Metal-sheathed Cable.—Fuses protecting the arrester may be omitted on circuits entering a building through metal-sheathed cable, provided the metal sheath of the cable is grounded and the conductors in the cable are No. 24 or smaller.

330. Installation of Conductors (National Electrical Code).—Conductors from the protector to the equipment or, where no protector is required, conductors attached to the outside or the inside of the building shall be separated from conductors of electric-light and power circuits as follows:

(1) **Open Conductors.**—Conductors shall be separated at least 2 in. from any light or power conductors not in metallic raceways or metal-sheathed cable unless permanently separated from the conductors of the other system by a continuous and firmly fixed nonconductor, additional to the insulation on the wire, such as porcelain tubes or flexible tubing.

(2) **In Raceways and Boxes.**—Conductors shall not be placed in any raceway, compartment, outlet box, junction box, or similar fitting with

conductors for light, power, or Class 1 signal or control circuits, unless the conductors of the different systems are separated by a partition. This restriction shall not apply to conductors in outlet or junction boxes, or similar fittings or compartments where such conductors are introduced solely for power supply to the remote-control or signal equipment.

(3) **In Shafts.**—Conductors may be run in the same shaft with conductors for light and power if the conductors of the two systems are separated at least 2 in., or if the conductors of either system are encased in noncombustible tubing.

(4) **Vertical Runs.**—Conductors bunched together in a vertical run shall have a fire-resistant covering capable of preventing the carrying of fire from floor to floor, except where conductors are encased in noncombustible tubing or are located in a fireproof shaft having fire stops at each floor.

The conductors would ordinarily be insulated, but the kind of insulation is not specified, as reliance is placed on the protective device to stop all dangerous voltages and currents.

331. Transformers for Class 2 systems supplying current from electric-light and power circuits shall be of a type approved for the purpose. They must be marked to show the primary voltage and whether or not of the current-limiting type.

332. Safety-control Circuits (National Electrical Code).—Circuits to safety-control devices, the failure of operation of which would introduce a fire or life hazard, shall be considered as Class 1 systems.

333. Grounding Outdoor Communication Circuits (National Electrical Code).—Equipment shall be grounded as follows:

a. Cable Sheath.—The metal sheath of aerial cables entering buildings and which are liable to contact with electric-light or power conductors shall be grounded or shall be interrupted close to the entrance to the building by an insulating joint or equivalent device.

b. Protector Ground.—The protector ground shall comply with the following:

(1) **Insulation.**—The grounding conductor shall have a $\frac{1}{32}$-in. rubber insulation and shall be covered by a substantial fibrous covering. Conductors approved for the purpose having less than $\frac{1}{32}$-in. rubber insulation or having other kinds of insulation may be used.

(2) **Size.**—The grounding conductor shall not be smaller than No. 18 copper.

(3) **Run in Straight Line.**—The grounding conductor shall be run in as straight a line as practicable to the grounding electrode.

(4) **Mechanical Injury.**—Where necessary, the grounding conductor shall be guarded from mechanical injury.

(5) **Electrode.**—The grounding conductor shall preferably be connected to a water-pipe electrode. In the absence of a water pipe, connection may be made to a continuous and extensive underground gas

piping system, to an effectively grounded metallic structure, or to a ground rod or pipe driven into permanently damp earth. Steam or hot-water pipes or lightning-rod conductors shall not be employed as electrodes for protectors. A driven rod or pipe used for grounding power circuits shall not be used for grounding signal circuits. The requirement for a separate driven electrode for signal circuit and for power-supply circuit grounding does not prohibit bonding together the signal and power grounding electrodes where such bonding seems desirable.

(6) **Electrode Connection.**—The grounding conductor shall be attached to a pipe electrode by means of a bolted clamp to which the conductor is soldered or otherwise connected in an effective manner. If a gas-pipe electrode is used, connection shall be made between the gas meter and the street main. In every case the connection to the grounding electrode shall be made as close to the earth as practicable.

334. Outside wiring of overhead conductors which enter buildings shall comply with the following National Electrical Code rules—Circuits which require protectors (see Sec. **329**) shall comply with subparagraph (1) of Sec. **330** and also the following:

a. Insulation, Single or Paired Conductors.—Each conductor, from the last outdoor support to the protector, shall have $\frac{1}{32}$-in. rubber insulation, except that when such conductors are entirely within a block the insulation on the conductor may be less than $\frac{1}{32}$-in., but not less than $\frac{1}{40}$-in. in thickness. In addition, the conductor, either individually or over the pair, shall be covered with a substantial fibrous covering. Conductors with rubber insulation of a thickness less than specified above, or conductors with other kinds of insulation, approved for the purpose, may be used.

b. Insulation, Cables.—Conductors within a cable of the metal-sheathed type, or within a cable having a rubber sheath of at least $\frac{1}{32}$-in. thickness and covered with a substantial fibrous covering, may have paper or other suitable insulation. If the metal or rubber sheath is omitted, each conductor shall be insulated as required in paragraph *a* of this section, and the bunched conductors shall be covered with a substantial fibrous covering.

c. On Buildings.—Open conductors shall be separated at least 4 in. from light or power conductors not in conduit or cable, unless permanently separated from conductors of the other system by a continuous and firmly fixed nonconductor additional to the insulation on the wires, such as porcelain tubes or flexible tubing. Open conductors exposed to accidental contact with light or power conductors operating at over 300 volts and attached to buildings shall be separated from woodwork by being supported on glass, porcelain, or other insulating material approved for the purpose. This separation is not required where fuses are omitted as allowed by the Code.

d. Entering Buildings.—Where a protector with fuses is installed inside the building, the conductors shall enter the building through a noncombustible, nonabsorptive insulating bushing, or through a metal raceway, except where the entering conductors are in metal-sheathed cable or pass through masonry. Raceways or bushings shall slope upward from the outside, or, where this cannot be done, drip loops shall be formed in the conductors immediately before they enter the building. Raceways shall be equipped with an approved service head. More than one conductor may enter through a single raceway or bushing. Conduits or other metallic raceways located ahead of the protector shall be grounded.

335. Lightning Conductors (National Electrical Code).—A separation of at least 6 ft. shall be maintained between signal conductors on buildings and lightning conductors.

336. Underground Circuits (National Electrical Code).—Underground conductors of signal or communication circuits entering buildings shall comply with the following:

a. Not with Electric-light or Power Conductors.—Underground conductors shall not be placed in a duct, handhole, or manhole containing electric-light or power conductors, except in a section separated from such conductors by means of brick, concrete, or tile partitions.

b. Underground Block Distribution.—Where the entire street circuit is run underground and the circuit within the block is so placed as to be free from liability of accidental contact with electric-light or power circuits of over 300 volts, the insulation requirements of subparagraphs *a* and *d* of Sec. **334** shall not apply, the conductors need not be placed on insulating supports, and no bushings shall be required where the conductors enter the building.

337. Additional Requirements for Installation of Class 1 Systems (National Electrical Code).

a. Wiring Method.—Conductors and equipment shall be installed in accordance with the general requirements for interior wiring.

b. Branch-circuit Conductors.—Branch-circuit conductors need not be individually protected against overcurrent if the operating voltage does not exceed 30 volts.

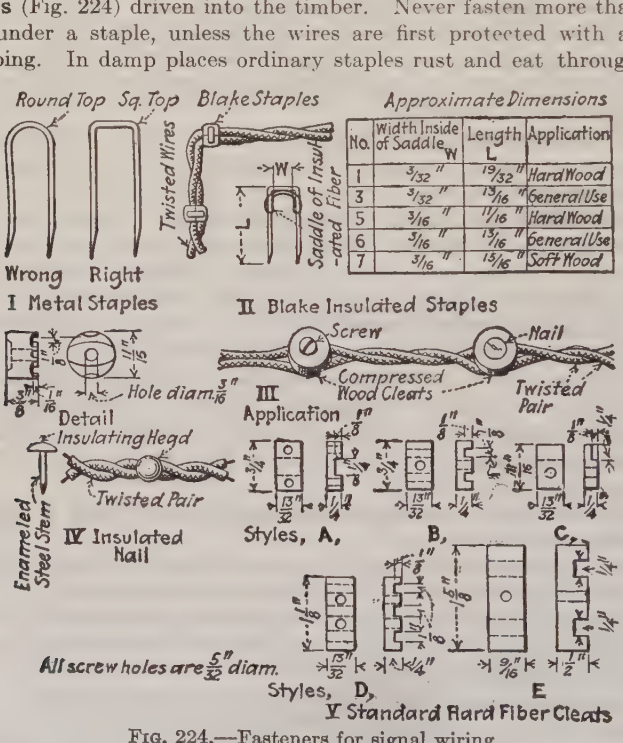
c. Conductor Insulation.—Conductors Nos. 18 and 16 shall have an insulation at least equal to that of Type RF-32, rubber-covered fixture wire or of other approved type. Conductors larger than No. 16 shall be rubber-covered Type R, thermoplastic Type T, or other approved type.

d. Conductor Size.—Conductors shall not be smaller than No. 18.

e. Overcurrent Protection.—Conductors shall be protected against overcurrent in accordance with the general requirements for interior wiring. Conductors of Nos. 18 or 16 shall be considered as protected by overcurrent devices of 15-amp rating or setting.

338. In installing signal wires in finished buildings the rubber-covered, twisted-pair copper wires may be used. They may be run along the top of the baseboard or along the picture molding. Where it is desirable to conceal the wiring and where expense is no consideration, the wires may be fished like lighting wires in concealed work. Where wires are bunched together in a vertical run, a fire-resisting covering, sufficient to prevent fire from traveling from floor to floor, must be provided.

339. Signal wires may be supported on wood in dry places with metal staples (Fig. 224) driven into the timber. Never fasten more than one wire under a staple, unless the wires are first protected with a tape wrapping. In damp places ordinary staples rust and eat through the



No.	Width Inside of Saddle W	Length L	Application
1	3/32"	19/32"	Hard Wood
3	3/32"	13/16"	General Use
5	3/16"	11/16"	Hard Wood
6	3/16"	13/16"	General Use
7	3/16"	13/16"	Soft Wood

FIG. 224.—Fasteners for signal wiring.

insulation. Electrolytic action may ensue, whereby the wire will be eaten through. It is very difficult to drive round-topped staples in straight; hence staples having square tops, of a style narrower than the ordinary double-pointed tacks, should be used. Zinc-coated staples are preferable to coppered ones. Insulating-saddle staples (see illustration II), are probably as cheap in the long run as the ordinary metal ones, as two wires can be safely held under one saddle staple, and time is thereby saved. Insulating-saddle staples secure the wire well at turns

and prevent the metal from cutting into the insulation. In stringing a long run, a saddled staple at the end will hold the slack until the intermediate staples are placed.

340. Cleats of compressed, impregnated wood (see Fig. 224) are good for supporting a twisted-pair conductor in an exposed place, as they are very neat in appearance. Either nails or screws can be used to hold them. The compressing of the wood prevents the cleats from splitting. They are particularly useful for runs over plastered surfaces and in other places where staples cannot be used. When stringing long runs of wire, compressed wood cleats at the run ends will hold the slack until the intermediate cleats are placed. These wood cleats cost less than those of either porcelain or fiber. They can also be used to support single wires, one wire under a cleat.

341. Insulated nails (Fig. 224, IV) having a metal stem and a head of insulating material are used for supporting twisted-pair conductors, and, although they are cheap, they do not support the wires so well as does the wood cleat. They do not hold a single wire well and do not properly hold back slack in long runs. The nails are made in different lengths and with heads of different colors to match surroundings.

342. Hard-fiber cleats (Fig. 224, V) are used where one or more single conductors are to be supported, but are not so good as the wood cleats, although they cost more. It is sometimes necessary to use them where the wire supported is too large for the standard wood cleat.

343. Wire for bell work in dry places is usually No. 18 copper, double cotton covered and paraffined. Where more than two or three bells are connected to the circuit, or where the circuits are long, No. 16 wire should be used. No. 14 is frequently used for battery wires. Rubber-covered, twisted-pair wires, like those used for interior telephone wiring by the telephone companies, can often be used to advantage in damp places or where the circuits are exposed. Number 20 wire, although sometimes used, is too small for reliable work. Annunciator and twisted-pair wire is made with insulating coverings of different colors, so one can be selected that will match the surroundings and thereby be inconspicuous. Cables of annunciator wire, which can be obtained with practically any number of conductors from 2 up to 200, are very convenient and economical for large installations. In perfectly dry locations, a cable having a paraffined, braided cotton covering can be used, but if it is to be exposed to dampness a lead-covered cable should be installed. By having the cable conductors covered with braids of different colors, the conductors can be readily identified. A kind of weatherproof wire called dampproof is quite satisfactory for exposed wiring in damp places. It is more expensive than annunciator wire, but it has a better appearance when installed.

344. The installation of signal wiring in wooden-framed buildings requires great care. The conductors are so weak mechanically, so poorly insulated, and frequently so numerous that, if work is not systematically

and thoroughly erected, trouble invariably results. The wires can be supported in unfinished houses by fastening them to the studs and joists with staples. In finished houses wires can be run behind a baseboard or under the molding at its top, or by prying up a floor board the wires

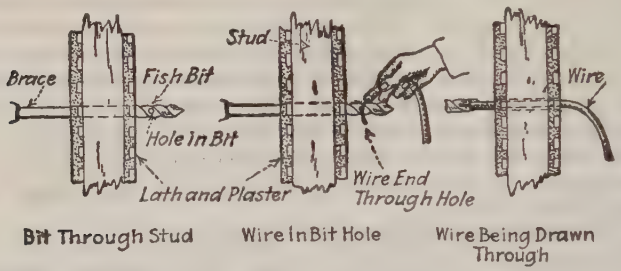


FIG. 225.—Use of steel fish bit.

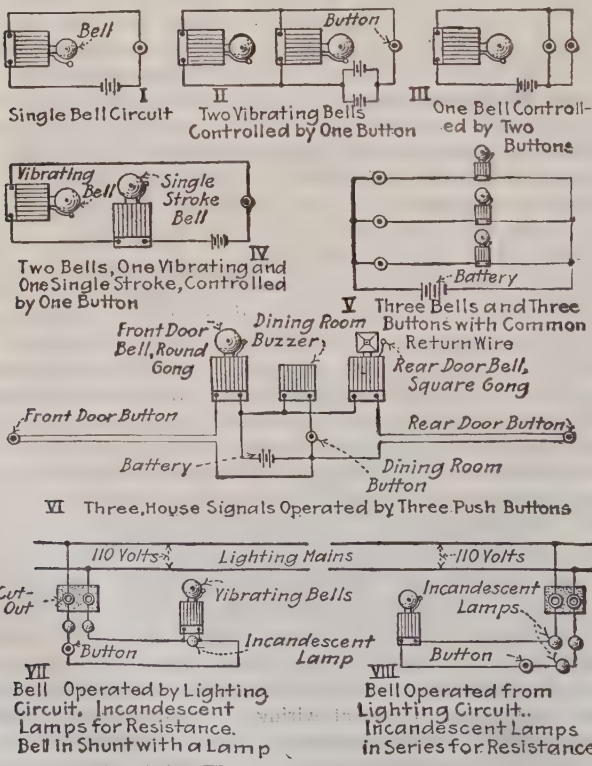


FIG. 226.—Elementary electric-bell circuits.

can be placed under it. A saw cut, into which the wires can be dropped, can be made in any joist that lies across the path of the wire. Wires can be run on the tops of picture moldings.

345. In fishing for vertical wires a piece of small chain 2 ft. long is attached to a length of strong cord. The chain and cord are pushed through a hole bored for the wire at the top of the partition, and the noise made by the chain when the cord is pulled up and down will indicate the location of any obstruction. With the obstruction located, the baseboard or floor board can be taken out and a hole can be bored or some other means adopted to provide a pocket whereby the chain can be reached.

346. The steel fish bit (Fig. 225) is a useful tool in installing signal wires. The bit has a hole in its end. After the bit has been bored through an orifice, the wire to be drawn through is made up through the hole and the wire and bit are together drawn back through the orifice. The use of a fish wire is thereby eliminated. In a floor or ceiling, the orifice having been bored, it may be more convenient to withdraw the bit first and then thread the wire through the hole at the end of the bit and push the bit back through the hole. Good bits of this type are so tempered that they will drill through wood, masonry, wrought iron, or structural steel.

347. Electric bell circuits are shown in Fig. 226. Many of these are quite simple but are included so that all will be together for the electrician's reference. Two ordinary vibrating bells will not work well together in series, so, when it is necessary to connect two or more in series, one should be a single-stroke bell, as in IV. A multiple arrangement II is preferable to a series arrangement, and the batteries for a multiple arrangement are more effective if connected in multiple. Try a series and a multiple arrangement of cells and ascertain which works best. Where several signal bells must be located together, gongs of different types (VI), each of which gives a different sound, can be used.

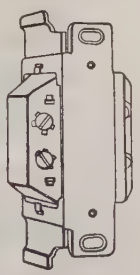


FIG. 227.—Bellringing transformer for switch-box mounting. (*Edwards Co.*)

348. Power Supply for Bell Circuits.—Although in the diagrams a battery has been shown as the power source, whenever an a-c supply is available a bell-ringing transformer stepping the voltage down to about 6 to 18 volts is usual (refer to Div. 5 for description of bell-ringing transformers). The transformer eliminates the trouble of having to replace batteries. It is of the high-reactance type, which has a no-load loss of only a few watts and which will deliver a maximum current of only a few amperes even when short-circuited. Types are available which can be mounted on the cover of a standard 3¼-in. outlet box, or, where appearance is important, a flush type with a louvered cover which can be mounted inside a switch box is available (Fig. 227).

On important signaling systems where the a-c supply is not fully dependable, a storage battery is used and kept charged with a copper oxide rectifier.

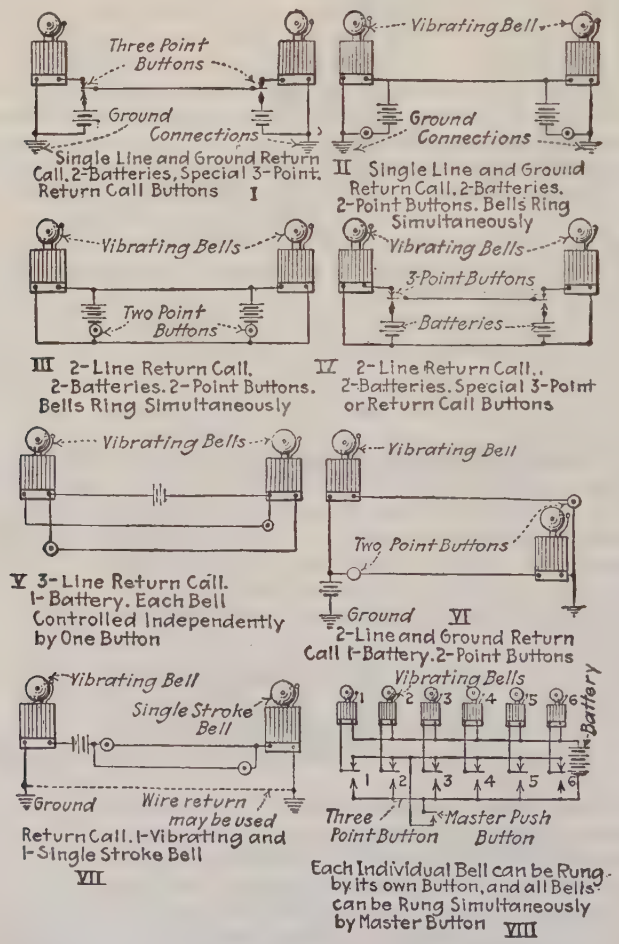


FIG. 228.—Return call and master-button electric-bell circuits.

349. Return-call bell circuits for different services are shown in Fig. 228. With these, when a station is signaled, the party called can signal back by pressing his button. In general ground return circuits are undesirable, as one ground on one of the normally ungrounded wires may render the system inoperative; furthermore, there are often "stray"

currents from electric railway circuits flowing in the earth, which may interfere with the operation of the bell circuits. With the arrangement

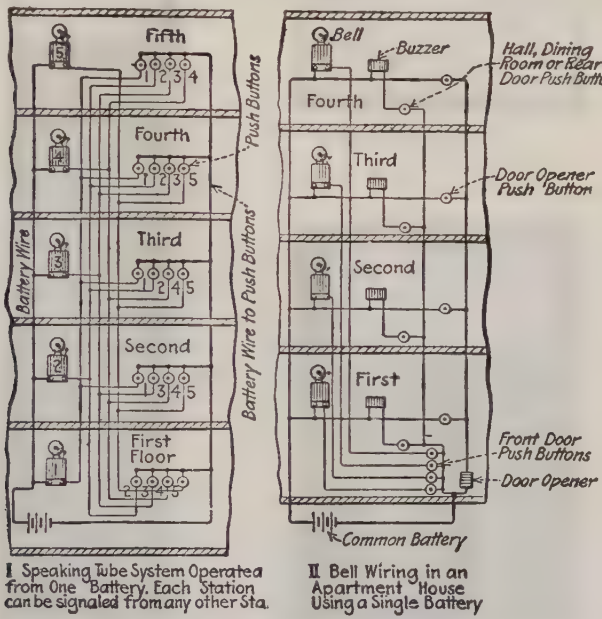


Fig. 229.—Apartment-house bell circuits.

of Fig. 228, VII, when the calling station is the one at the single-stroke bell, the caller may be sure that the called station is ringing, because it is the vibrating bell at that station that causes the single-stroke bell to ring.

350. Apartment-house and speaking-tube, bell-wiring circuits are shown in Fig. 229. One battery serves for all stations. Frequently a wire larger than the other wiring is used for the battery wire, which supplies all the stations.

351. Electric bells of different types are shown in Fig. 230. The vibrating bell is the one commonly used. The single-stroke bell can be used in series with a vibrating bell, which will open and close the circuit and thereby make the single-stroke bell also operate. Door chimes are frequently used instead of bells. They have a plunger which strikes against a bar or hollow tube to produce a pleasing musical note. The

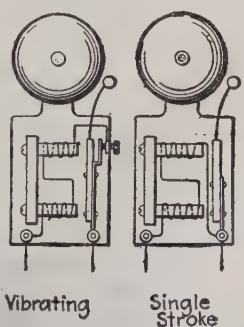
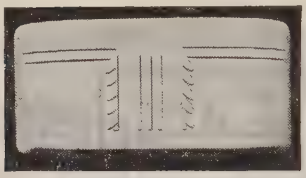
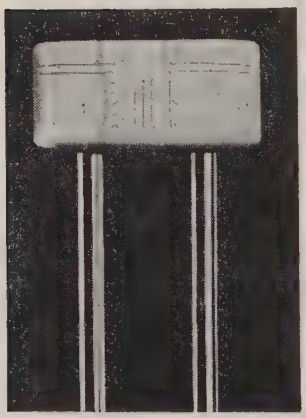


Fig. 230.—Electric bells of different types.



I. Enclosed-bar type.



II. Short tube.

III. Cathedral.

FIG. 231.—Door chimes. (*Edwards & Co.*)

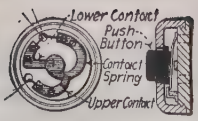


FIG. 232.—Three-point push button.

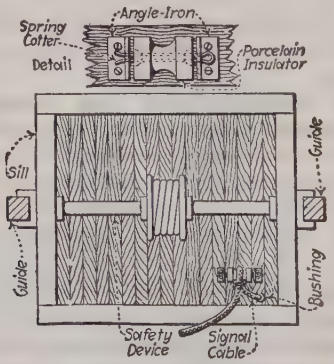


FIG. 233.—Bottom of elevator showing method of attaching cable.

enclosed-bar and short-tube (Fig. 231, I and II) are made with either a single-note or a double-note type. With the double-note type a single note sounds for the bell push from one door and a double note from the bell push from another door. The cathedral chimes (Fig. 231, III) play a series of musical notes.

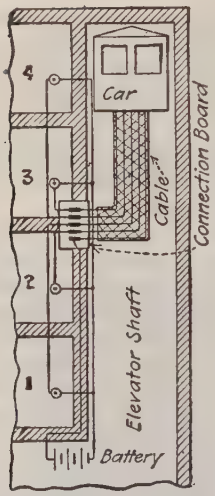
352. A double-contact, three-point or return-call push button (Fig. 232), is used in return-call bells and annunciator circuits. Applications of push buttons of this type are shown in the diagrams.

353. Annunciator circuits are shown in Figs. 234 and 235. With an elevator annunciator a cable having as many conductors as there are push buttons and one additional battery conductor is required. One end of this cable is attached to the car as shown in Fig. 233, and the other is made fast midway up the elevator shaft and should be connected to the push-button wires with binding posts on a connection board. The connection board is of great convenience in locating trouble. It is a good plan to install a cable having one more conductor than is actually required, so that a spare will be available in case of trouble.

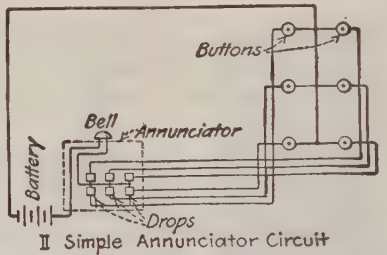
Annunciators cannot be operated successfully in multiple because of the many paths that are afforded the signaling current through annunciators so connected. In Fig. 234, III is shown one correct method of connecting two annunciators installed at different locations and operated from the same buttons and battery. Either one or the other of the annunciators can be thrown into service with the six-point switch. If two annunciators are to operate simultaneously the drops of one must be connected in series with the drops of the other. In V is shown an incorrect method of connecting two annunciators. With it, when one button is pressed there are several paths for the current and it will divide and flow as shown in the lower diagram and may, unless the annunciator adjustments and battery strength are just right, throw all the drops. Annunciators connected in accordance with this method will ultimately give trouble.

The method of connection of IV is used where attendants are signaled from annunciators located in different parts of the building during certain periods of the day and from a centrally located annunciator at other times. Either the local annunciator bells or the common annunciator can be shunted out when necessary with the short-circuiting switches shown. Figure 235, I shows a diagram of a Parker, Carter & Wilkins return-call annunciator system. With this system there is a considerable saving in wire, as only one direct wire is required from a room to the annunciator. Two common battery wires are around the house.

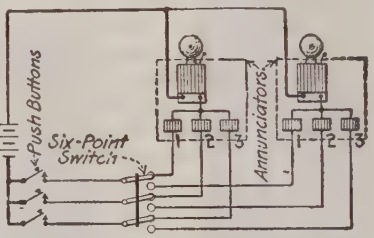
Figure 235, II and IV shows two methods of accomplishing the same end. That of II is probably preferable for the average installation because (1) the signaling current does not pass through any button except that being pressed, (2) single-contact, not double-contact, push buttons are used, and (3) only one battery wire is carried to the rooms.



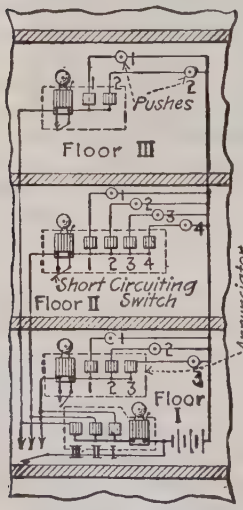
I-Wiring for an Elevator Annunciator



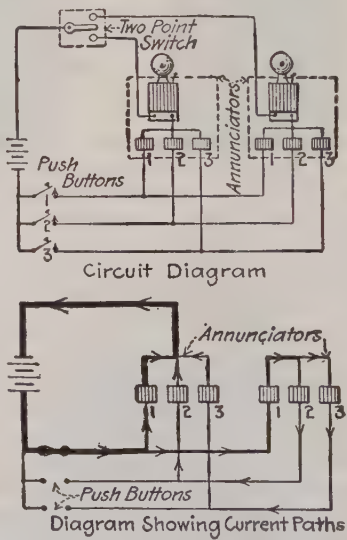
II Simple Annunciator Circuit



III-Correct Method of Interconnecting Two Annunciators



IV-Annunciators on Each Floor and a Common Annunciator



V-Incorrect Method of Interconnecting Two Annunciators

FIG. 234.—Annunciator circuits.

With the fire-alarm system III, when any one of the switches is closed all the annunciator stations are signaled.

354. Bell-ringing transformers (Fig. 236) should always, where there is alternating current, be used for operating signaling systems such as those for bell and annunciator service. A well-made bell-ringing trans-

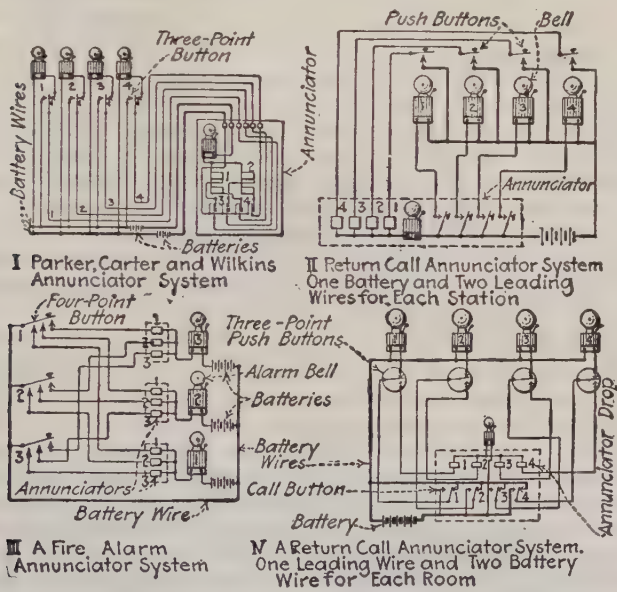


Fig. 235.—Fire-alarm and return-call annunciator circuits.

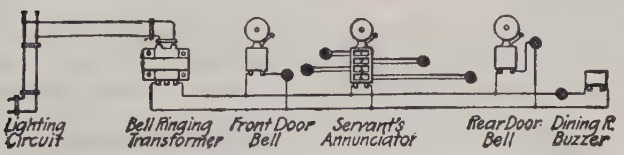


Fig. 236.—Application of a bell-ringing transformer.

rmer will last forever. Consult the local inspector as to his installation equirements before putting in a bell-ringing transformer, as there have een misunderstandings in regard to this matter. The National Elec- ical Code rules specify that the transformers shall be of special design nd that the primary wiring shall be installed in accordance with the les for light, power, and heat wiring and that the secondary wiring shall e installed in accordance with the rules for signal-system wiring. It is ell to try out a bell-ringing transformer with any instrument that is to

be operated by it, if the instrument has coils of many turns (such as an annunciator), before final connections are made, because the impedance of these coils to the alternating current sometimes "chokes" the current and renders operation less satisfactory than would be expected, judging from the secondary-voltage rating of the transformer. A well-designed, bell-ringing transformer requires very little energy for its operation.

355. Burglar-alarm systems ("Standard Handbook") are simply modifications of call-bell systems; the bell circuit being closed whenever a door, window, transom or skylight, etc., is opened. More elaborate alarm systems entail the use of an annunciator indicating which window or door, etc., has been opened; a continuously ringing bell; a silent test switch to show that every window, door, etc., in the house has been properly closed; switch for testing bell and battery; a general switch for cutting out the alarm system during the day or whenever it is not required; lock switches for admitting persons with proper keys without sounding the alarm; attachments for lighting an incandescent lamp or gas-jet automatically when the alarm sounds so that the annunciator drop may be visible, and numerous other refinements.

The chief requisite of an alarm system is the certainty of action of the apparatus and contacts. Since the apparatus may stand months and even years without being called into action, rubbing contacts, german-silver springs, etc., are largely employed. Wires, contacts, etc., should be concealed and should be installed in a first-class manner.

356. There are two classes of burglar-alarm system: open circuit and closed circuit. In open-circuit systems the circuit or circuits to doors and windows throughout the building are normally open and when the circuits are closed by a door or window being opened the alarm is sounded. In closed-circuit systems the circuit throughout the building is normally closed, and current is flowing in it. When it is opened the alarm is sounded.

357. Open-circuit systems are shown in Figs. 237, 238, and 239. Some arrangement—a continuous-ringing bell or drop—must be provided whereby the circuit through the alarm bell will remain continuously

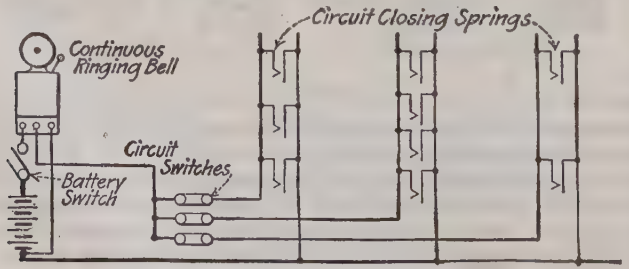


FIG. 237.—Simple open-circuit burglar-alarm system.

closed if a house circuit is closed instantaneously. In setting the system for the night, the battery switch and the circuit switches are all opened. Then the battery switch is closed and the circuit switches are closed one

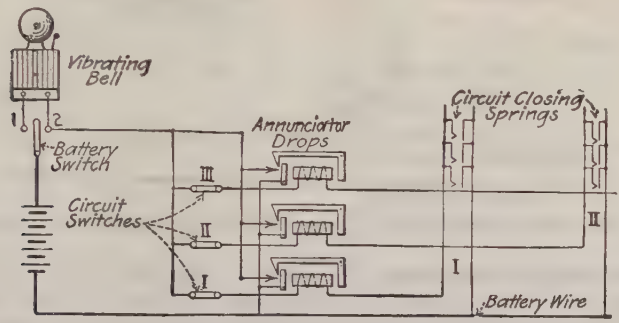


FIG. 238.—Open-circuit burglar-alarm system with alarm annunciator.

at a time, thereby locating any circuit on which there is trouble or on which a window may have been left open. Open-circuit systems are usually installed in preference to closed-circuit systems because of their simplicity.

358. One objection to the open-circuit system is that, if the wires should be cut, no protection is afforded, the alarm being then inoperative. When properly installed, however, the cutting of wires is a very rare occurrence. To guard against this possibility, a closed-circuit system may be installed in connection with the open-circuit system, the window, door, and other contacts being arranged to open the circuit of a relay which thereby makes contact with the bell circuit. This system will give the alarm when the wires are cut, or when the closed-circuit battery is run down, or when a window, door, etc., has been opened. A straight closed-circuit system may also be installed.

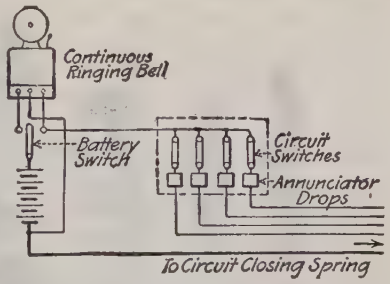


FIG. 239.—Open-circuit burglar-alarm system using an annunciator in combination with a continuous-ringing bell.

359. Closed-circuit systems are more sensitive than open circuit but are more liable to disarrangement. Figure 240 shows an installation with two house circuits, but usually one house circuit suffices. Fine bare copper wire (No. 24 gage) can be used for the house circuits and may be strung in front of doors, windows, and objects to be protected so that its breakage will open the circuit and set off the alarm. Gravity cells

are used for the closed-circuit battery, and Leclanche cells for the open-circuit battery.

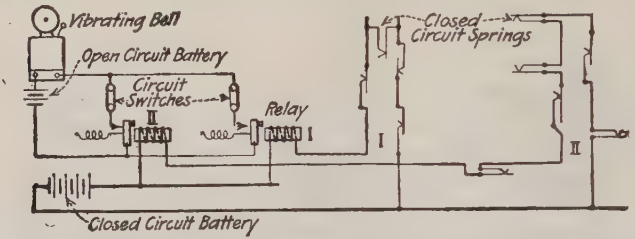


FIG. 240.—Closed-circuit burglar alarm with two alarm circuits.

360. Burglar-alarm fittings are shown in Fig. 241. Figure V shows burglar-alarm attachments for protecting windows, skylights, blinds, etc. A wire or string is attached to the ring and is drawn so as to break the contact. Further tension on the wire or string or its severance will establish the contact and give the alarm. Alarm springs for shades are shown in Fig. VI. The string of the shade is attached to the arm or hook so as to break the contact. Any interference with the setting makes

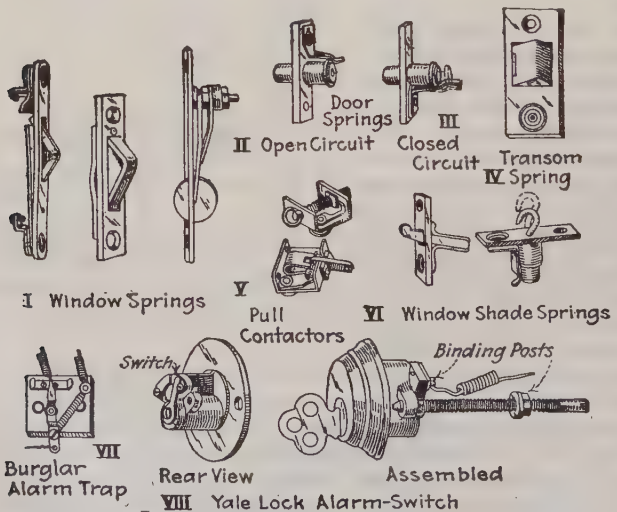


FIG. 241.—Burglar-alarm fittings.

contact and gives warning of intruders. A lock burglar-alarm switch is shown in Fig. VIII. This is placed on the doorframe so that persons

with proper keys can enter without giving the alarm. Turning the key opens the bell circuit.

A burglar-alarm trap is shown in Fig. VII. This simple device has a great many applications. The illustration shows the trap in a balanced position, *i.e.*, the switch is not making contact. The string connected to the switch may be attached to a window, door, or skylight, or stretched across a hall, open doorway, etc., to be protected against intruders. The slightest disturbance of the string will draw the switch to one side and make contact, and if the string is broken the spring will draw the switch to the opposite side and make contact so that in either case an alarm is given. An auto-drop or constant-ringing attachment is shown in Fig. 242. The bell circuit is closed automatically and is kept closed as long as desired. The drop is placed in the bell circuit, and when the circuit is closed by a push button, door, or window spring the circuit-closer drop is operated by an electro-magnet and keeps the circuit closed until the drop is raised again.

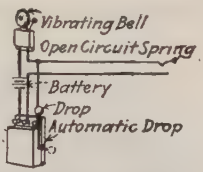


FIG. 242.—Constant ringing attachment.

Instead of contacts in windows, doors, etc., electric mats are sometimes used. An invisible electric mat is placed under the carpet or other floor covering, which when trod on or touched by the foot sounds an alarm or signal in any part of the house by closing the bell circuit. By this means windows may be left open for ventilation and protection still obtained.

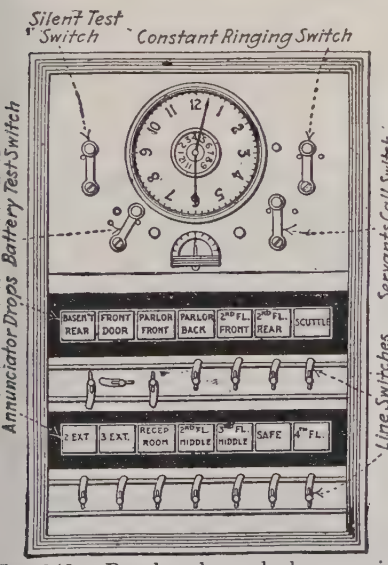


FIG. 243.—Burglar-alarm clock annunciator.

361. Clock burglar alarms ("Standard Handbook") (Fig. 243) may be had which automatically disconnect sections at predetermined times. These may also be fitted with a constant-ringing switch, a servants' call switch, an incandescent lamp, or an attachment for automatically lighting the whole house in case of an alarm. Switches are provided for testing each circuit leaving the annunciator, for testing the bell and line, and for testing the battery.

362. The installation of a burglar-alarm system (open circuit) is shown in Fig. 244. It is to be understood that all the windows in one room are connected in multiple so that only one drop on the annunciator is required for each room. Figure 245 shows the arrangement of a simple, closed-circuit, burglar-alarm system. All the contacts are arranged to open the closed circuit when disturbed; this releases the armature of the relay, which is instantly drawn by the spring to complete the bell circuit and give the alarm. This arrangement requires the use of both closed-circuit and open-circuit batteries and although a trifle the more expensive is the most reliable system that can be installed. In this system the alarm is given, the room indicated, and the lamps throughout the building turned on whenever the circuit is opened. In closed-circuit systems a resistance should be placed in the circuit when the alarm is not set ("Standard Handbook").

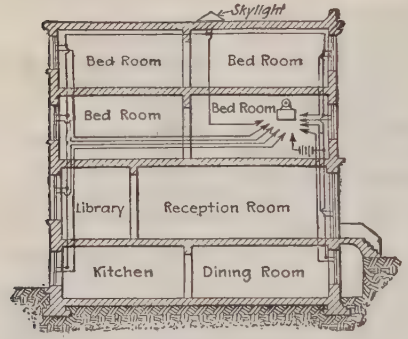


FIG. 244.—Open-circuit burglar-alarm system.

Circuit-opening or -closing springs are usually placed in window frames and door jambs. In installing springs be careful that the door or window fits snugly enough so that the spring will lie in its normal position when the door or window is closed.

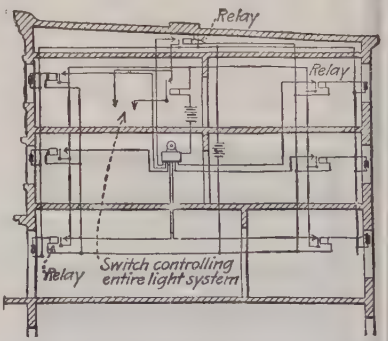


FIG. 245.—Closed-circuit burglar-alarm system. Annunciator indicates room and switch throws on all lights.

WIRING FOR SPECIAL OCCUPANCIES

363. The National Electrical Code should be consulted for special rules on installations in the following occupancies:

1. Elevators
2. Emergency lighting.
3. Garages.
4. Motion-picture studios.
5. Theaters, including motion-picture projectors.

6. Trolley wires in buildings.
7. Sound-recording equipment.
8. Organs.
9. Radio equipment.
10. X-ray and high-frequency equipment.
11. Electric welders.

DESIGN OF INTERIOR WIRING INSTALLATIONS

364. Factors Affecting Wiring Layouts ("Standard Handbook").—In conduit work the space available often dictates that the feeders be split up into two or more feeder lines. Conduit larger than 2 in. in diameter is not easily handled, and even if the run were such that 2-in. conduit could be easily installed it would be preferable to install smaller conduit and divide the feeders so as to guard against complete shutdown, should anything happen to the feeders.

In reinforced-concrete floors a cross section of the floor must be studied to see that there will be sufficient space for the reinforcing rods, conduit or raceways, and necessary thickness of concrete. This is especially true where conduits cross. The local building code should be consulted to see what restrictions are placed on floor installations. A minimum thickness of 1 in. of concrete over conduits and raceways should be used to prevent cracking.

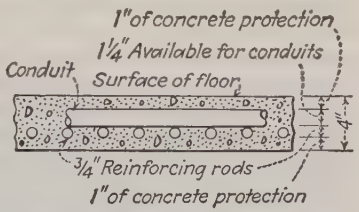


FIG. 246.—Study of space available for conduits in reinforced concrete floors.

Example.—The building code may allow floors 4 in. thick with ¾-in. reinforcing rods located with 1 in. of concrete covering the underside (Fig. 246). This would mean that there is a minimum space of 1¼ in. between the top of the reinforcing rods and the top of any conduit. For this installation, ¾-in. conduit, which has an outside diameter of 1.05 in. (Table 61), would be the largest size allowable. There could be no crosses of conduit because even two ½-in. conduits would take up $2 \times 0.84 = 1.68$ in. of space, which is more than the 1¼ in. available.

In brick walls there must be two thicknesses of brick in order to conceal conduits, and the distance between them must be studied to determine the maximum size for vertical runs of conduit. For bare-conductor feeders a layout of the cross section of the chase should be made to determine the space required for the insulators, feeders, and hardware, and for working space for installing them. These are only a few of the possible examples where space for wiring must be considered. Very often the mistake is made of installing feeders just large enough to carry the present load, and when additions are called for the feeders are overloaded, and additional feeders must be installed at great expense. Conduits for feeders and mains should be of sufficient size to permit the installation

of feeders or mains of a carrying capacity of 150 per cent of the presen connected load.

365. In selecting a system for wiring for light one should be use whereby 115 volts or thereabouts can be impressed on the lamp terminals Nominal 115-volt incandescent lamps, including those of voltages o from, say, 110 to 125 volts, are more efficient and cheaper and have longe lives than those for higher voltages. Lamps of nominal voltages of abou 32 volts are seldom used now and require excessive expenditures fo copper conductors. The three-wire system is much more economica of copper than a two-wire system and therefore should be used for feeder and mains in installations of any consequence; then the two-wire systen is used for branches. Three-phase systems can be used for lighting a elsewhere described (see Index) and can be used to advantage in industria plants where the use of constant-speed motors makes the use of th three-phase system desirable.

366. Wiring methods to be used are determined by a consideratio of national and local code requirements, reliability, appearance, an cost. In planning a wiring installation, Tables 23 and 25 should firs be consulted to determine which methods of wiring are allowable fo the particular occupancy and electric system being considered. Then th cost of the various allowable methods should be weighed against th appearance, the degree of protection afforded, reliability, and probabi years of service which will be realized. Both the cost of material an cost of labor must be considered.

a. For Residences.—Armored cable concealed in the partitions is th most practical, giving good reliability at moderate cost. Where a some what cheaper installation is desired, the nonmetallic-sheathed cable ma be used. Sometimes this is used for a few large-sized circuits such a to the electric range where the difference in cost is considerable, even the rest of the wiring is armored cable. The expense of rigid condu is usually not justified except in very large residences of the highest gra of construction. Where the highest degree of adequacy for convenien outlets is desired the multioutlet assemblies should be employed for th part of the wiring.

b. In wiring buildings on farms, one must consider that the ca income of the average small farmer is so small that he cannot afford a but the cheapest wiring installation which will be safe and give reasonab length of service. For the house, nonmetallic-sheathed cable or armor cable would be employed. For the barns and other outbuildings, op wiring on insulators or nonmetallic-sheathed cable would be employe The nonmetallic-sheathed cable will afford the neater appearance.

c. For rewiring of old buildings of residential or commercial occ pancy, surface metal raceways, armored cable, nonmetallic-sheath cable, or electrical metallic tubing are the usual expedients. Surfa

metal raceways give the best appearance if the wiring must be exposed. Armored cable is the most practical for that part of the wiring which can be fished through the partitions. For areas which were not originally supplied with sufficient convenience outlets, nonmetallic surface extensions are often advantageous. Where relocation of lighting outlets is desired in a room of commercial occupancy, underplaster extensions or surface metal raceways are generally employed.

d. For small commercial buildings and apartment buildings of frame, or brick and frame construction, armored cable concealed in the partitions is generally the most practical.

e. For office and public buildings of fireproof steel, concrete, and terra-cotta construction, the cost of wiring is only a small percentage of the total cost of the building. In order to keep the offices rented to business firms, the electric system should provide the very best in appearance and adequacy of service. Therefore the wiring should be concealed, employing rigid metal conduit for ceiling lights and feeders and underfloor raceways or cellular-metal-floor raceways for desk outlets for power and signaling circuits.

f. For industrial buildings the rigid- or flexible-conduit system is generally used for branches, with open wiring, bus ways, or conduit for feeders.

g. For large-sized main feeders the method of wiring should be considered very carefully because the high unit costs may make a considerable difference in the total cost of the installation.

Very often, combinations of wiring methods are used in the same building, each method being used where its advantages make it desirable.

367. In considering the type of insulation to use for interior wiring refer to Div. 2 for complete information on the various types of insulated wires and to Table 23 of this division for allowable applications. Rubber or thermoplastic insulation is used for all general applications except for unusually hot locations, permanently dry locations, and for corrosive-vapor locations. Factors to be considered in selecting the type of insulation to employ are discussed in the following sections.

368. Comparison of Types R and RH Rubber-insulated Wires.—The heat-resisting grade has a carrying capacity about 20 per cent more than the Code grade except for sizes No. 14 to No. 10 where they are the same as the Code grade. On the basis of carrying capacity alone for relatively short runs, where voltage drop is not a deciding factor, type RH is about 20 to 25 per cent cheaper for currents of 35 amp. and over. In most cases one size smaller conduit can be used with type RH wire. This means that the conduit cost will be about 25 per cent less also.

Example.—Suppose it is desired to carry a 250-amp. balanced load with a three-phase, four-wire circuit. Referring to Table 18*A* of Div. 11, 350,000-cir. mil, Type R or 250,000-cir. mil, Type RH wire can be used. Referring to Table 21 of Div. 11, four 350,000-cir. mil wires require a 3½-in. conduit, whereas four 250,000-cir. mil wires require only

a 3-in. conduit. A 3-in. conduit is about 25 per cent cheaper than a 3½-in. one. T wire itself will be about 25 per cent cheaper, and the labor of installing less, owing to t handling of smaller sizes of wire, conduit, and fittings.

When the length of circuit is such that the size of wire is determine by voltage drop, Type R is cheaper because no use can be made of t increased carrying capacity of the other grade.

369. If different types of rubber-covered wires are used in the sam building, care should be taken to keep them in separate conduits or rac ways, since the carrying capacity of the wires in the raceway must l limited to the carrying capacity of the lowest grade of wire insulatio in the raceway in order that none of the insulation will be subjected to temperature in excess of the value given in Sec. **24.**

370. In permanently dry locations, varnished-cambric wire, whic has a carrying capacity 30 per cent greater than Code-grade rubber b costs only about 20 per cent more, may be considered for feeders. I general for carrying capacities of 100 amp. and up, the cost for wi and conduit will be only about three-quarters as much with varnish cambric as it will be with Code-grade rubber. Also it will provide superior installation as far as long life and freedom from trouble are co cerned. The varnished-cambric wire will be about 15 per cent cheap than Type RH wire. One should consider, however, that, owing to t relatively limited application, varnished-cambric wire is not usual kept in stock by dealers or even in district warehouses, and deliver from the factory may take 3 or 4 weeks. Also, as a direct result of th special-order situation, the price of varnished-cambric wire varies co siderably with the length ordered. The price comparisons made in th section are on the basis of lengths of 1,000 to 5,000 ft. For lengt between 500 and 1,000 ft. the price is about 8 per cent greater, and f lengths between 300 and 500 ft. the price is about 40 per cent more. would not pay at all to purchase less than 300 ft. Finally, the maki and taping of splices is not quite so easy with varnished cambric as wi rubber. For locations where these disadvantages are not a factor, su as a building which has three or four four-wire, equal-sized feeders abo 100 ft. long, with no splicing required, and where the order for wire c be placed 4 weeks or so before the job is to start, varnished cambric is quality selection. Since varnished cambric cannot be used in siz smaller than No. 6 except by special permission, it is generally not us for branch circuits.

371. In hot locations the maximum room temperature will general be the determining factor in selecting the type of wire insulation employ. Refer to Sec. **24** for allowable temperatures of insulation.

372. Where there is a choice between types of conductors the size each should be determined and the most economical one selected. using Tables 18 and 18*A* of Div. 11, divide the current desired to be carri

in the wire by the correction factor at the bottom of the table corresponding to the maximum room temperature. Select from the table the size of wire which will carry that resultant current.

Example.—A feeder carrying 350 amp. is to be run with open wires on the upper wall of a room containing an electric furnace. Determine the maximum operating temperature and the type of wiring to use. A thermometer placed on the upper wall reads 130°F. on a day when the outside temperature is 75°F.

Solution.—On a hot summer day the outside temperature may reach 95°F., a 20° increase, which will raise the temperature in the furnace room to 130° + 20° = 150°F. Referring to Table 16 in Div. 1, this corresponds to about 65°C. If the correction factors corresponding to 70°C. are used, the actual maximum operating temperature will be 5°C. less than that allowable for the type of insulation selected, and some margin of safety will be allowed. Referring to Sec. 17 and Table 18 of Div. 11, the choice is between asbestos-varnished-cambric, Type AVA with a 0.71 correction factor and varnished cambric with 0.52 correction factor. The resultant current for the AVA = 350/0.71 = 493 amp.; for the varnished cambric = 350/0.52 = 673 amp. Referring to Table 18 of Div. 11, 493 amp. requires a 250,000-cir. mil AVA wire, and 673 amp. requires a 600,000-cir. mil, varnished-cambric wire. Since the asbestos-varnished-cambric wire would be less than half the size of the varnished-cambric one, the asbestos-varnished-cambric wire should be selected.

373. For corrosive-vapor locations the authority enforcing the National Electrical Code must be consulted to determine whether it will allow rubber-covered, varnished cambric; one of the asbestos-varnished-cambric types, weatherproof; or some other type of insulation. In general the rubber-covered type is allowed for very mildly corrosive vapors but not for acid fumes, and weatherproof, slow-burning, or asbestos open wiring is allowed for the more severely corrosive vapors.

374. For rewiring of buildings using existing conduits or raceways which are concealed and which it would be impracticable to replace with larger sizes owing to structural considerations, the National Electrical Code allows the conduits to be filled to a greater percentage of their area than they may for new work (see Table 24 of Div. 11).

In selecting the type of conductor to use in rewiring of existing conduits, Type R should normally be used for branch circuits and Type V for feeders.

Example.—A building was wired with feeders of three No. 2/0 Type R wires in 2-in. conduit. How much may the carrying capacity of the feeder be increased by changing to Type V wire with a 120/208 volt, three-phase, four-wire system?

Solution.—The existing feeder was good for $2EI/1{,}000 = (2 \times 120 \times 150)/1{,}000 =$ 36 kw. of balanced lighting load. The 150 amp. was the carrying capacity of No. 2/0 Type R wire prior to 1940.

Referring to Table 21 of Div. 11, a 2-in. conduit will take four No. 3/0, Type V wires. According to Table 18*A* of Div. 11, the current-carrying capacity of No. 3/0, Type V wire is 210 amp. Note that the three-conductor table is used without the multiplier of 0.8, because the neutral conductor does not carry any current at the time of balanced load in the line wires.

The new feeder is good for $3EI/1{,}000 = (3 \times 120 \times 210)/1{,}000 = 75.6$ kw. The voltage drop = $kLI/A = (11 \times 100 \times 210)/211{,}600 = 1.1$ volt for a 100-ft. run, which is within the 1 per cent allowable for lighting feeders (see Div. 3).

Therefore, the carrying capacity may be practically doubled, from 36 to 75.6 kv assuming that the feeder supplies three-phase panel boards or three two-wire or thre wire panel boards. With any other arrangement of panel boards, the carrying capaci will be limited to the load on the heaviest loaded phase, and the full capacity may not realized.

375. The National Electrical Code classifies lighting and appliance branch circuits according to the rating of the fuse or circuit breaker whic protects the circuit, and the Code provides certain restrictions on th rating of outlets and equipment to be supplied, as given in Table 376.

376. Lighting and Appliance Branch Circuits

Rating of branch circuit, amp.	15	20	30	50
Type of lamp holders allowed	Any	Any	Heavy duty	Heavy duty
Minimum size of circuit wires	14	12	10	6
Minimum size of tap conductors, fixture wires and cords	14	14	14	12
Rating of receptacles, amp.	Not over 15	15 or 20	20 or 30	50
Maximum load, amp.	15	20	30	50
Maximum rating of any one portable appliance	12	16	24	40 if in use f long period
Maximum load if load will continue for long periods of time, amp.	12	16	24	40
Maximum load if motor operated appliances are supplied, amp.	12	16	24	40
Total rating of fixed appliances:				
a. If that is only load supplied	15	20	30	50
b. If receptacles or lighting units are also supplied	7.5	10		

377. In planning the wiring for a residence secure the floor plans of th building and locate the outlets and switch circuits as shown in Fig. 24 Consult with the local public-utility company concerning their servic equipment requirements with respect to type and sequence of equipmen location of meter, etc. Decide whether fuses or circuit breakers should b used for circuit protection. If the power company uses an outdoor met located outside the kitchen or back hall, circuit breakers located in th inside wall at that point will probably be the best. If an indoor met is specified, consideration should be given to running two or three N 8-wire circuits to distribution centers on the first and second floors, which points circuit breakers will control the branch circuits. Bran

fuses located at the service switch should only be used where the circuit-breaker system does not seem well adapted or where the lowest cost system is indicated.

378. The number and location of switch, lamp, convenience-outlet, and special-purpose outlets should next be decided on. Refer to Table 380 for general guidance, although personal taste and requirements should have considerable weight. Some persons prefer ceiling outlets, others wall outlets. The installation of a central ceiling outlet in all rooms should be encouraged even though sufficient wall and convenience outlets for portable lamps are installed.

In wiring a residence, ample provision should be made for portable lamps and appliances by installing a liberal number of plug outlets, or convenience outlets, as they are called. In Sec. 380 the recommended number of convenience outlets that should be considered is indicated. These are the minimum specifications as recommended by the "Handbook of Residential Wiring Design." This handbook was prepared

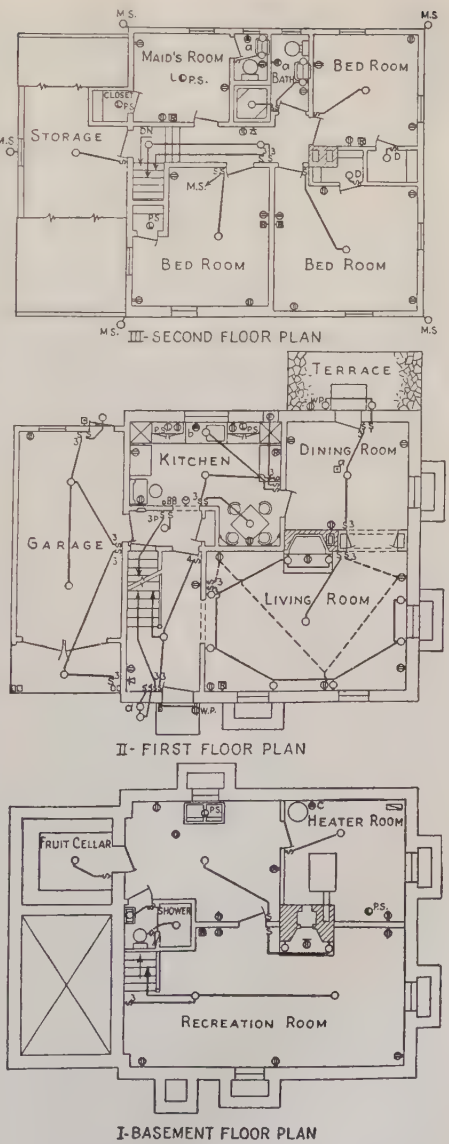


FIG. 247.—Layout of outlets for a residence. (*Handbook of Interior Wiring Design.*)

by the Industry Committee on Interior Wiring Design, sponsored b several organizations including the Edison Electric Institute, the Natio Electrical Contractors Association, and the National Electrical Man facturers' Association.

Rooms with a single door should have the ceiling outlet controlled by switch near the door; rooms with two doors more than 10 ft. apart shou have a three-way switch at each door. Generally speaking the switch should be in the same room as the lights they control, with the excepti of those places where it is more convenient to control them from the oth side of the wall, such as closets, front hall, porch, and cellar. Th should be located on the wall, 4 ft. from the floor at the point where t door opens. A door switch can be inserted in the jamb of a closet do whereby a lamp in the closet will be automatically lighted when the do is opened. This should be used in few closets, however, as it is expensive item and has the disadvantage that if it is desired to leave t door open in the daytime the light continues to burn. Hall outlets shou be controlled by three-way switches near the front door and on the seco floor.

The cellar light should be controlled by a switch and red pilot lam located on the first floor near the cellar stairs, so that it may be turned when starting down the stairs. The pilot lamp serves as a warning case the light is not turned off after the person returns from the cell Bathroom lamp outlets should be arranged so that shadows will not cast against windows. A master switch can be located in the owne bedroom and wired to turn on certain lights all over the house in ca of emergency, independently of the regular switches. Where possib convenience outlets should be located back to back on the walls so as minimize the wiring. Also, if second-floor outlets are located direct above first-floor outlets, the wiring is facilitated, as it is easier to ma vertical runs of wiring than to cut through studs for horizontal runs.

379. The size of service conductors is required by the National El trical Code to be not less than the carrying capacity for the load comput in accordance with the instructions of Div. 3. Regardless of the lo the service conductor must not be smaller than No. 6, except by spec permission or for installations with not more than two branch circui By special permission or for installations with only two branch circui they may be No. 8. For installations supplying only one branch circ the service conductors must not be smaller than the conductors of t branch circuit and in no case smaller than No. 12. The Industry Co mittee on Interior Wiring Design recommends that the size of the serv equipment should be not less than given in Table 382. It is much m expensive to remove the service equipment and service conductors a to install new larger rated items, when new larger wattage applian are added, than it is to pay the few additional dollars for the proper s equipment in the initial installation.

380. Recommended Residential Outlet Requirements

("Handbook of Residential Wiring Design," prepared by the Industry Committee on Interior Wiring Design)

Space	Lighting outlets	Type of circuit	Convenience outlets	Type of circuit	Special-purpose outlets	Type of circuit
Living room, library, den, sun room	1 ceiling outlet, wall-switch-controlled, 2 outlets where room length exceeds width. Wall, cove, or valance outlets may be substituted	Gen.	No point at wall line more than 6 ft. from an outlet; wall spaces 3 ft. or more to have outlet; outlet in mantel shelf. Two or more outlets switch-controlled	Gen.		
Dining room, dinette, breakfast room	1 ceiling outlet, wall-switch-controlled	Gen.	No point at wall line more than 10 ft. from an outlet; wall space 3 ft. or more to have outlet	App.		
Kitchen, kitchenette, pantry	1 ceiling outlet, wall-switch-controlled; 1 outlet at sink, switch-controlled	Gen.	1 outlet for every 4 lin. ft. frontage of kitchen work surface. 1 outlet at refrigerator location	App.	1 for range 1 for clock 1 for fan 1 for dishwasher waste-disposal unit	Ind. Gen. Gen. Ind.
Laundry	1 ceiling outlet at washing center 1 ceiling outlet at ironing center. Wall-switch control for one ceiling outlet	Gen.			1 for washer 1 for hand iron or ironer	App. or Ind. App.
Bedrooms	1 overhead outlet, wall-switch-controlled	Gen.	No point at wall line more than 6 ft. from an outlet. Wall spaces 3 ft. or more to have outlet	Gen.		
Bathrooms, lavatories	1 outlet each side mirror, wall-switch-controlled 1 ceiling outlet in shower compartment, wall-switch-controlled 1 ceiling outlet in rooms 60 sq. ft. and over, wall-switch-controlled	Gen.	1 near mirror	Gen.		
Recreation room	1 ceiling outlet for each 150 sq. ft. of floor area, wall-switch-controlled. Wall, cove, or valance outlets may be substituted	Gen.	No point at wall line more than 10 ft. from an outlet; wall spaces 3 ft. or more to have outlet; outlet in mantel shelf	Gen.		

Recommended Residential Outlet Requirements (*Continued*)

*Space	Lighting outlets	Type of circuit	Convenience outlets	Type of circuit	Special-purpose outlets	Ty of ci cui
Reception hall	1 ceiling outlet, wall-switch-controlled. Wall, cove, or valance outlets may be substituted	Gen.	No point at wall line more than 10 ft. from an outlet; wall spaces 3 ft. or more to have outlet	Gen.		
Halls	1 outlet for each 15 lin. ft., wall-switch-controlled	Gen.	1 for each 15 lin. ft.	Gen.		
Stairways	1 outlet on each floor, illuminating head and foot of stairway. Each outlet to have separate switch control at head and foot of stairway	Gen.				
Closets	1 outlet in closets 3 ft. or more deep or having a floor area of 10 sq. ft. or more	Gen.				
Exterior entrances (front and trade)	1 or 2 outlets, wall-switch-controlled	Gen.	1 at front entrance	Gen.		
Covered porches	1 outlet for each 150 sq. ft. porch floor, wall-switch-controlled	Gen.	1 for each 15 lin. ft. of house wall bordering porch	Gen.		
Terraces and patios			1 for each 15 lin. ft. of house wall bordering porch	Gen.		
Basement utility space	1 outlet for each enclosed space, 1 for workbench and 1 for furnace location; sufficient additional outlets to provide 1 for each 150 sq. ft. of open space	Gen.	1 at workbench location, 1 at furnace location	Gen.	1 for electrical equipment used in connection with furnace operation	Ind
Accessible attics	1 outlet, wall-switch-controlled. 1 outlet for each enclosed space	Gen.	1 for general use	Gen.		
Garage	1 interior wall-switched outlet for one- or two-car garage plus 1 for each additional two cars. 1 outlet for exterior lighting, multiple-switch-controlled if garage is detached from house	Gen.	1 for one- or two-car garage, plus one for each additional two cars	Gen.		

Gen —Outlets supplied by 15-amp. general-purpose circuits.
App.—Outlets supplied by 20-amp. appliance circuits.
Ind.—Outlets supplied by individual equipment circuits.

381. For dwelling occupancies the National Electrical Code requires that a sufficient number of branch circuits be installed to carry a load of 3 watts per square foot of floor area, not including open porches, garages, nor unfinished or unused spaces unless adaptable for future use. In addition to these circuits, the receptacle outlets in the kitchen, laundry, pantry, dining room, and breakfast room must be supplied by one or more 20-amp. branch circuits which do not supply any other outlets. The Industry Committee recommends two such circuits.

In every kitchen, dining room, breakfast room, living room, parlor, library, den, sun room, recreation room, and bedroom, one receptacle outlet must be provided for every 20 linear feet or major fraction thereof of the total gross distance around the room as measured horizontally along the wall at the floor line. Insofar as practicable these outlets shall be spaced equal distances apart. Unless close to the wall, floor outlets do not count. At least one receptacle of a 3-pole type designed for grounding must be installed for the connection of laundry appliances.

382. Service-entrance standards for dwellings as recommended by the Industry Committee on Interior Wiring Design.

Floor area of dwelling, sq. ft.	Ampere capacity of service conductors	Rating of service equipment, amp.		
		Switch	Fuse	Circuit breaker
Up to 1,000	60	60	60	70
1,000–1,500	65	100	70	70
1,500–3,000	85	100	90	90
3,000–4,000	100	100	100	100

383. Multiple-family Buildings or Apartments.—The recommendations for residences may be applied to individual apartments for lighting, convenience, and switch outlets. Where central heating is supplied, it is unlikely that an electric heater will be used in the bathroom or that many heavy-duty appliances will be used at one time. Therefore a single 20-amp. branch circuit supplying convenience outlets in dining room and kitchen generally will be sufficient in addition to a 15-amp. branch circuit for every 500 sq. ft. of floor area. It is recommended that a range circuit of the type explained in Sec. **381** be installed for each apartment.

For nonrentable areas under the control of the building management the following rules from the "Handbook of Interior Wiring Design," prepared by the Industry Committee on Interior Wiring Design, represent good practice:

1. *Entrances.—a.* Sufficient outlets shall be installed to provide electrical service consistent with the general architectural treatment, but in no

case shall there be less than one outlet for an outside lantern, or two fo outside wall brackets.

b. At least one ceiling outlet shall be installed for each 150 sq. ft. of vestibule space.

c. At least one wall outlet shall be installed over each group of lette boxes covering a lineal distance of 8 ft. or less.

2. *Lobby or Main Hallway.—a.* At least one ceiling outlet per 125 sq. ft of floor area shall be installed provided that:

(1) No area has outlets spaced more than 15 ft. apart.

(2) No elevator door or stair well is more than 6 ft. from the neares ceiling outlet.

b. At least one convenience outlet shall be installed for every 12 ft. o wall space for portable lamps and general utility purposes (vacuun cleaners, floor polishers, etc.).

c. Provision shall be made for additional outlets to furnish such illumi nation as is demanded by the architectural treatment. This may be i the form of decorative wall brackets, urns, pedestals, built-in units, etc.

3. *Upper Hallways.—a.* At least one ceiling outlet shall be installed pe 150 sq. ft. of floor area, provided that:

(1) No area has ceiling outlets spaced more than 15 ft. apart if arrange on alternate circuits; or 30 ft. if adjacent outlets are on the same circuit.

(2) No elevator door or staircase is more than 6 ft. from the neares ceiling outlet.

(3) No section of a hallway not in a straight line from another shall b without at least one ceiling outlet.

b. At least one convenience outlet shall be installed per floor, wit additional outlets spaced so that no point in a hallway is more than 25 ft from a convenience outlet.

4. *Hall Switches.—a.* All ceiling outlets plus the outlets for entranc lighting shall be controlled by switches.

b. Where all ceiling outlets on any one floor are controlled by a singl switch, this switch shall be of a type or shall be located so as to be inac cessible to the general public.

c. Where more than one switch controls the ceiling outlets on a par ticular floor, at least one switch shall be inaccessible to the general public This switch shall control outlets installed under the following provisions

(1) It must control the outlet nearest the stair well or the elevator door

(2) It must control outlets so that the spacing between any two is no greater than 30 ft.

(3) It must control an outlet in every space not in direct line from th outlet near the stair well or the elevator door.

5. *Stair Wells.—a.* Where enclosed stair wells are installed (such as i fireproof construction) there shall be an outlet for lighting on each landing

b. Where exit lights are required, they shall be installed in accordanc with all rules and regulations covering their use.

6. *Basement Areas.*—Lighting outlets shall be provided in basement areas on the basis of at least one ceiling outlet per 200 sq. ft., plus additional outlets and necessary switch control if such basement areas are available to tenants for laundry, storage, or other purposes.

7. *Oil Burners, Stokers, Air-conditioning Equipment, etc.*—Circuits shall be individually provided for each such piece of equipment in accordance with the size and rating of each motor or heater.

8. *Elevators.*—Power and light feeders for elevator service shall be of the size required by the elevator manufacturer.

384. The arrangement of the service and feeders will depend on the system of metering employed. Where each apartment is to be metered and billed for all its power, a meter service switch and meter should be provided for each apartment and one or two for the building management. These should be located in rows along the walls in the basement. Each apartment must be on an individual feeder from the meter service switch. The load on the feeder should be computed in accordance with the instructions given in Div. 3. If an electric range is not supplied by the feeder, a two-wire feeder is usually sufficient. Where the feeders can be grouped and the building is supplied by a three-phase, four-wire, a-c supply, three apartments can be supplied from a single neutral. If an electric range is supplied, a three-wire feeder should be used for each range. When the power company will bill the building management on a lower rate for power than they do for lighting, two meters with separate circuits for each should be provided. Where there are more than six meter service switches, the service must be brought in through a single fused service switch, the size to be determined in accordance with the instructions of Div. 3. Where the power is to be billed to the building management and included in the rent, the circuit is brought in through a single fused service switch as before.

Circuits for either one or two meters, depending on whether the power company bills the power on a separate rate from the lighting, should be provided. A distribution center with a safety-enclosed fused knife switch or circuit breaker for each feeder should be installed. The feeders can then supply distribution panel boards in the halls on each floor, or one feeder can be installed for each three apartments. The latter plan is preferred, as it facilitates a change to the other metering system in case a different policy should prove advisable in the future. Frequently a combination of these two systems is employed in which the management is billed for and provides certain definite services, such as the electric range, refrigerator, or air-conditioning equipment, the probable cost of which is relatively easy to determine and much cheaper when paid for on a wholesale rate taking advantage of the low demand factor which applies to a large number of customers. Then the customer has a separate service through his individual meter for lighting and small appliances. The method of wiring is with armored cable or nonmetallic-sheathed

cable for small buildings of frame construction. Conduit wiring is usually employed for the larger buildings of fireproof construction.

385. With any of the above plans each apartment should have its own distribution panel board containing fuses or circuit breakers for the branch circuits. Fuse panels are cheaper, but circuit breakers will reduce labor in calls for service due to short circuits in portable cords and appliances. In either case the panel board should be located high up on the wall of the kitchen or hall so as to be relatively free from tampering.

386. Adequate Wiring for Lighting and Convenience Outlets in Commercial and Public Structures.—It is very important in designing the interior wiring for a building to make adequate provisions not only for the present demands but also for the probable future demands. The levels of illumination demanded by industry and commerce are being constantly increased. In order that a building may keep pace with this advancement without an excessive expense in the reconstruction of its wiring, it is necessary that the wiring be more than adequate to provide merely for the present needs. Double carrying capacity can be provided in the original wiring installation for less than 25 per cent additional cost. In order to provide a guide for adequate wiring, the following recommendations from the "Handbook of Interior Wiring Design" are given:

1. *Outlet Location.—Commercial and Public Occupancies.* *A.* Ceiling Outlets for General Illumination.—Whenever possible, ceiling outlets should be uniformly spaced and located so that the spacing will be approximately the same in both directions. In **offices** and **schoolrooms,** the spacing between adjacent outlets shall not exceed the distance from floor to ceiling. In other interiors, the space may be extended to 1½ times the ceiling height. The space between an outlet and a wall should not exceed one-half of the average distance between outlets. In **halls** and **corridors,** spacing should not exceed 20 ft.

In locating outlets on any floor plan, building construction features should be considered, especially ceiling beams. These are not always shown on the floor plans, yet they may seriously affect a lighting layout. This is particularly true for indirect lighting.

B. Stores.—Convenience Outlets.—There shall be installed at least one convenience outlet for each 400 sq. ft. of floor area or major part thereof, these outlets to be uniformly distributed over the entire area. Preference shall be given to the placing of these outlets in supporting columns and side walls, but no part of the floor area shall be more than 15 ft. from an outlet.

C. Stores—Outlets for Window Illumination.—Provision for show-window illumination shall be made by (1) a junction box on wall or column at suitable height above transom bar or possible false ceiling to which all circuits of show-window reflectors or spotlights can be connected or (2) individual outlets spaced as recommended below.

For medium screw lamp holders, outlets for show-window reflectors

should be located 12 to 18 in. apart. For mogul screw lamp holders, outlets for show-window reflectors should be located 15 to 24 in. apart. Whenever more than one circuit per window is necessary, adjacent outlets should be on different circuits.

For spot or floodlights, at least two outlets per window shall be symmetrically placed, with an additional outlet for every 8 ft. (or major fraction) in excess of 16 ft.

D. Stores—Convenience Outlets in Show Windows.—In or near the floor of each window, there shall be installed at least one convenience outlet for each 50 sq. ft. of platform or floor area used for window display, but in no case shall there be less than two convenience outlets per window.

E. Stores—Outlets for Case Lighting.—Outlets shall be provided in the floor or wall for termination of the circuits for show-case and wall-case lighting. Such outlets shall be suitably located for connection to the lighting equipment and shall be governed by the standard loads as listed in Sec. **201,** Div. 10 (Show Cases, Wall Cases).

F. Offices and Schools, Convenience Outlets.—In each separate office room with 400 sq. ft. or less of floor area, there shall be installed at least one convenience outlet for each 20 lin. ft. of wall space. In each separate office with more than 400 sq. ft. of floor area, there shall be installed at least four convenience outlets for the first 400 sq. ft. of floor area and at least two outlets for each additional 400 sq. ft. or major fraction thereof. Outlets should be placed at suitable locations to serve all parts of the office space. Certain offices, as, for example, professional and display offices, require many more outlets than are specified above, and the wiring needs must be individually studied where such probable occupancy is known.

For typical schoolrooms at least one convenience outlet shall be placed along the front wall and at least one along the rear wall.

G. Offices and Stores—Fans.—Unless made unnecessary by provision for complete air-conditioning, outlets for fans shall be installed on the basis of at least two for each 400 sq. ft. or major portion thereof. Such outlets shall be placed approximately 7 ft. above the floor and shall be of a type from which the fan may be mechanically suspended.

H. Stores—Signs.—Where no other equivalent provision is made for sign lighting, a rigid metal conduit or electrical metallic tubing, not smaller than 1 in., shall be run to the front face of the building for each intended or probable individual store occupancy. Such raceway shall terminate outside the building at a point suitable for connection to the sign and shall terminate inside the building at a cabinet. Feeder capacity to this cabinet and service capacity shall be based upon a sign load of not less than 50 watts per lineal foot of store frontage, only the frontage on the principal street being considered if the store faces more than one street. Space provision shall be allowed for the connection and placement of a time switch to the sign circuit.

2. *Branch Circuits.*[1]—The minimum number of branch circuits shall be based on the present connected load as follows:

a. For two-wire, 15-amp. circuits, the load per circuit shall not exceed 1,000 watts.

b. For multiwire, 15-amp. circuits, the load shall not exceed 1,000 watts between each outside wire and the neutral.

c. For circuits designed for heavy-duty lamp holders, the load per circuit shall not exceed 1,500 watts for No. 10 wire, 2,500 watts for No. 8 and 3,000 watts for No. 6.

The following considerations of wire size and circuit runs shall apply:

d. No wire smaller than No. 12 shall be used for any circuit.

e. Where the run from a panel board to the first outlet of a lighting branch circuit exceeds 50 ft., the size of wire used shall be at least one size larger than that determined by any of the above considerations. The calculated size may be used between outlets.

f. Where the run from a panel board to the first outlet of a convenience outlet circuit exceeds 100 ft., No. 10 wire or larger shall be used for such run.

g. No runs longer than 100 ft. between panel board and the first outlet of a lighting branch circuit shall be made, unless the intended load is so small that the voltage drop can be restricted to 2 per cent between panel board and any outlet on that circuit. To avoid this condition, panel boards should be relocated, or additional panel boards installed.

The following considerations in regard to combinations of outlets shall apply:

h. No convenience outlet shall be supplied by the same branch circuit that supplies ceiling or show-window lighting outlets.

i. Outlets for show-window spotlights shall be on separate circuits from general show-window outlets.

j. The number of convenience outlets included on one circuit shall be based on the listing in the following table.

3. *Outlets per Circuit:*

Location	Max.
Barber shops, beauty parlors, etc.	2
Medical, dental, and similar offices	2
Store show windows (for spotlights)	3
Store show windows (at floor)	6
Display areas in retail stores	6
School classrooms	6
Manufacturing spaces	6
Office spaces	8
Storage spaces	10

4. *Circuit Control.*—Suitable provision shall be made for the control of all circuits except those supplying convenience outlets only, and control

These standards are based upon 15-amp. protection of branch circuits. If local regulations limit the load on branch circuits to less than these requirements, the wattage and area limits herein specified must be proportionately reduced.

of the latter circuits is recommended. Circuits may be controlled individually, in groups, or by a combination of both methods.

In a retail store, individual control at the panel boards by means of circuit switches or circuit breakers is usually preferable. In most other occupancies, control should be provided by means of local switches or circuit breakers. Frequently it is necessary to provide two or more switches for the local control of outlets supplied by a single branch circuit.

Provision shall be made for control of all circuits supplying a single sign by means of an external manually operable switch or circuit breaker, and in each case a suitable time switch shall also be provided to effect the same control.

In a retail store, each circuit supplying outlets in one or more show windows shall be individually controlled, and provision shall be made for the installation of a time switch for group control of all such circuits.

Group control of circuits for general illumination or for special decorative effects, by means of remote-control switches, is desirable in certain large spaces such as large reading rooms, museums, art galleries, and ballrooms.

5. *Panel Boards.*—On each panel board one spare circuit shall be provided for each five circuits utilized in the initial installation. Where flush-type cabinets are used, provision shall be made for bringing a corresponding number of circuit conductors to the ceiling of the story served, or to the ceiling of the story immediately below, or to both points. Such provision may consist of circuit conductors or empty raceways terminating in boxes suitably located for future extensions.

Provision shall be made for control of show-window lighting by such grouping of circuits to a panel board as to enable a time switch to be suitably-installed.

6. *Feeders. A.* Carrying Capacity.—The carrying capacity of each feeder or subfeeder shall be based on the number of separate circuits which it supplies, computed as follows:

(1) Overhead Lighting Circuits.—Assumed as having 1,000 watts per circuit for each 15-amp. circuit.

(2) Convenience-outlet Circuits.—Assumed load of 1,000 watts per circuit.

(3) Spare Panel-board Circuits.—Assumed load of 500 watts.

(4) Nonitemized and Heavy-duty Additional Circuits.—Specific load for which designed.

To the total of these four, such demand factors as permitted by the National Electrical Code should be applied. (Refer to Div. 3 for additional information.)

B. Provision for Future.—In all determinations of feeder size, consideration should be given to increasing the capacity of the initial system by 50 per cent to provide for future growth at a minimum of unwarranted

expense. In cases where an ultimate feeder size does not exceed No. wire, the excess capacity should be installed immediately. In othe cases, one of the following methods should be made a part of the origina layout.

(1) The installation of oversize raceways, so that the conductor installed may be withdrawn at any time and replaced by conductors o suitable larger size.

(2) The installation or arrangement of the installed equipment so tha additional feeders can be installed later at a minimum of expense t furnish the ultimate capacity.

(3) The installation of feeders of excess size.

C. VOLTAGE DROP.—Feeders and subfeeders shall be of such size tha the total voltage drop from any panel board to the point where connectio is made to the lines of the utility supplying services shall not exceed 1 pe cent (see Div. 3 for method of calculation). To compute such drop, th ultimate demand as calculated above shall be used wherever the wire siz based on such demand is installed immediately. Where provision for th future is made in some other way (oversize raceways, etc.) the voltag drop shall be computed on the basis of the carrying capacity of the wir used.

7. *Feeder Distribution Center.*—A feeder distribution center in the form of a panel board, switchboard, or group of enclosed switches or circui breakers shall be provided for the control and protection of each feeder.

Except where oversize feeders are provided in the original installatio as recommended in the preceding section, provision shall be made at th feeder distribution center for the connection and suitable protection o feeders of increased size or of supplemental feeders. This may be accom plished by providing additional protective devices as part of the origina installation, or by so designing the original equipment that space, bu capacity, and facilities for making connections will be available.

8. *Service-entrance Adequacy Standards:*

Initial load, amp.	Service switch, amp.	Conductor size, gage No. or cir. mils	Initial load, amp.	Service switch, amp.	Conductor size, gage No. or cir. mils
1– 23	60	8	118–133	200	4/0
24– 33	60	6	134–150	400	4/0
34– 47	100	4			
48– 60	100	2	151–167	400	250,000
61– 67	100	1	168–183	400	300,000
			184–200	400	350,000
68– 83	200	1/0	201–217	400	400,000
84–100	200	2/0	218–267	400	500,000
101–117	200	3/0			

9. *Service Conductors and Equipment.*—The minimum capacity of the service required for the initial load depends on the total number of feeders supplied by it, whose individual loads are determined as specified in subparagraph 6. Where applicable, demand factors as permitted by the National Electrical Code may be used (see Sec. **45** of Div. 3). To determine the probable required ultimate capacity of the service conductors and equipment, 50 per cent should be added to the calculated initial load.

Where the calculated initial load does not exceed 267 amp., service conductors and equipment having the capacity needed for the ultimate load should be included as part of the original installation. The recommended equipment for various initial loads is tabulated in item 8.

Where the initial load exceeds 267 amp., a study should be made of each individual case to determine what provision should be made for a future increase in the load.

387. There are five points that must be considered in designing the wiring layout for a large building (Knox, "Electric Light Wiring"):

1. Control of groups of receivers (other than hall or night lights) from the main switchboard.
2. Control of hall lights from the main switchboard.
3. Maximum load that should be served by one feeder.
4. The best maximum limit for the size of the feeder conductors.
5. The proportion of the total voltage drop that can be allowed in feeders and mains.

Each of these items will be separately considered in the following paragraphs. By a receiver is meant any device that consumes electrical energy.

388. Control of Groups of Receivers (Other than Hall or Night Lights) from the Main Switchboard.—Where it is desirable to control a group of receivers from the main switchboard in the basement, a separate feeder must be carried from it to each group to be so controlled. Usually the feeder system can be laid out without regard to the control of the room lights, because, as a rule, they do not have to be controlled from the switchboard. It is usually advisable to have each of the lower floors, up to and including the ground floor, on a separate switch, as these floors often require light when the others do not. Special lighting appliances such as sign, clock-dial, and outside dome lights require separate feeders from the switchboard, because they are turned on and off at set times from the switchboard. Certain motors may require similar control. In hotels the feeder switches are never opened except in case of accident so, from a control standpoint only, it is not necessary to subdivide hotel feeders. Where tenants of portions of buildings pay for the light they use, it is often desirable to carry a separate feeder from the switchboard to each tenant's suite so that all meters can be located together at the switchboard. Suites can be metered separately by cutting meters in the mains at the suites, but this may be undesirable.

389. The control of hall lights from the main switchboard is an important consideration. In private dwellings it does not usually pay to install a separate feeder for the hall lights, and it may not be necessary in a hotel where attendants are constantly passing in the halls. In a majority of public buildings, however, separate control of the hall lights is very desirable if not necessary. The usual problem is, then, whether there shall be one or two sets of hall-light feeders. With two sets of feeders for hall lights, local switches may be eliminated and control effected entirely from the main switchboard. Two sets of hall feeders increase the cost of installation, but the saving in energy usually justifies them. By arranging two sets of feeders, one set serving, say, one-third the hall lights and the other the remaining two-thirds, the smaller group can be used for dark days and for an all-night circuit, and a saving in energy will result. Where there are two sets of hall lights thus controlled, the wiring of outlets should be such that there will be a uniform distribution of light, whichever set is lighted. Where tenants pay for the energy used in their suites, a separate feeder for the hall lights is indispensable.

390. Maximum Load That Should Be Served by One Feeder.—It is impossible to give a hard and fast rule covering this feature. The total load in the building, the available space for the switchboard, the method of control desired, and the cost all influence a decision. The load should always be somewhat subdivided to localize trouble and so that, in an isolated plant, the engineer can disconnect portions of the load, while he is getting another machine on the line, when the load comes on suddenly.

391. Best Maximum Limit for the Size of Feeder Conductors. On a basis of cost alone it is usually cheaper to run a few large conductors than a great number of small ones. It does not pay, however, to use conductors larger than 1,000,000 cir. mils. When greater capacity is required it is cheaper to subdivide, so that several conductors will have the aggregate capacity required. For alternating currents, conductors larger than 700,000 cir. mils are not desirable because of skin effect. Often the space available for conductor runs makes it necessary to use small conductors. Each case must be decided on its merits.

392. The Proportion of the Total Voltage Drop That Can Be Allowed in Feeders and Mains.—Distribution of drop is discussed in another section, and it is there stated that it is usual to confine certain proportions of the drop to the feeders, certain proportions to the mains, and certain proportions to the branches. As the allowable voltage drop determines the size of a feeder or main it is evident that the layout of feeders and mains for any given job will in a measure depend on the drop distribution. Where the load on an incandescent-lighting feeder exceeds 1,000 watts, a three-wire feeder should be used to ensure good voltage regulation and maximum economy of copper.

393. To design the wiring layout for a large building, make a sectional-elevation drawing of the structure and a plan drawing of each floor.

Indicate the receivers (lamps and motors) on the plans and then locate panel boxes. Panel boxes should be placed so that they can be readily reached and so that the branch circuits, mains, and feeders can be run to them. Compute the load on each panel box and indicate it on the drawing at the box.

Now lay out the mains and feeders. First decide whether the hall or public lights will be controlled separately, or together with the private lights from the main switchboard, because this feature affects the arrange-

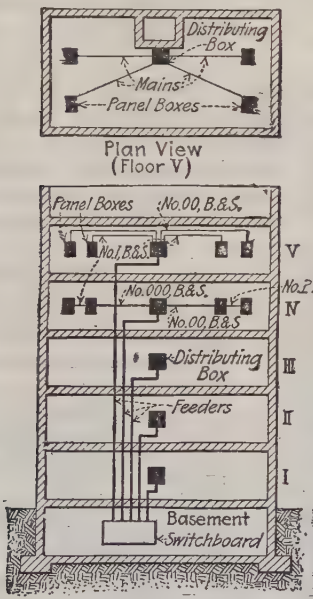


Fig. 248.—Individual feeder to each floor.

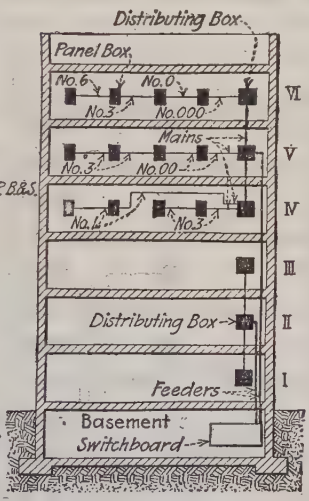


Fig. 249.—One feeder serving three floors.

ment of the feeders and possibly that of the mains. Next decide (note conditions outlined above affecting this matter) whether there should be a separate feeder to each floor as in Fig. 248, or whether several floors or portions thereof will be served by one feeder (Figs. 249 and 250). Where it is not necessary to control the loads separately on the different floors and where the conductor size will not be prohibitively large, the cheapest and probably the best arrangement is to serve several or possibly all floors with one feeder. Usually the only limit to the number of floors that may be served with one feeder is the refinement of control that is required from the main switchboard. It is frequently necessary to make several tentative layouts and computations before the most desirable arrangement is found. Make a tentative arrangement of mains and

feeders and compute the conductor sizes by rules given elsewhere. If the tentative scheme does not prove satisfactory lay out another and try that. Motors, and groups of motors, unless very small, should be served by independent feeders.

394. Examples of feeder, main, and panel-box layouts in large buildings are shown in Figs. 248 to 253. These are shown to illustrate principles rather than actual installations but each method shown could be effectively applied in some certain case. Elevator shafts often provide excellent runways for vertical, conduit-encased feeders. Mains and feeders should be installed of a size 25 per cent larger than actually necessary, to provide for growth.

395. Feeders and Mains to the Floors of Buildings.—In buildings covering large areas, several panel boxes per floor may be required. These panel boxes may each be served by a separate riser if vertical wireways are convenient, or it may be better to install but one riser to

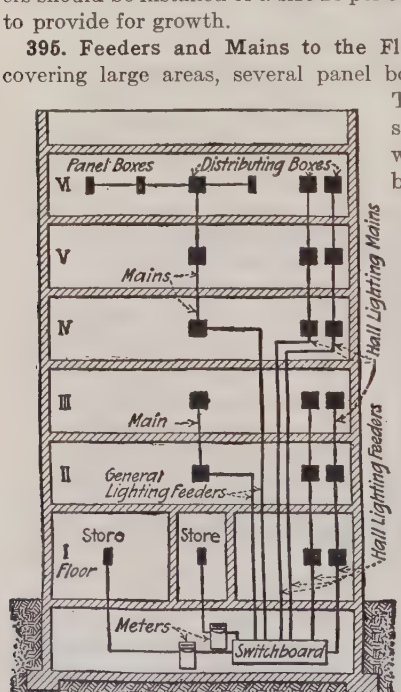


FIG. 250.—Two sets of lighting feeders.

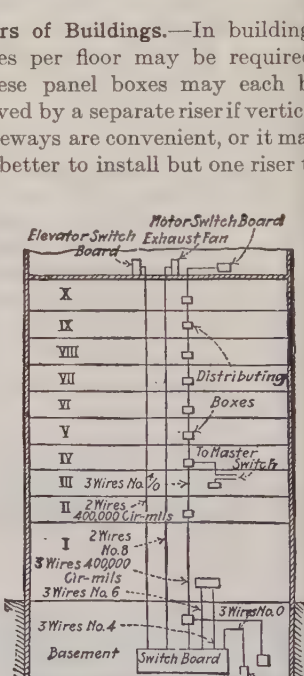


FIG. 251.—An actual feeder layout.

each floor and distribute through horizontal mains to the panel boxes on the floor as in Fig. 249. In an installation where the feeders and mains are all vertical there need be no feeder runs in the floors. The construction of the building and the flexibility of control desired largely determine these points. An excellent arrangement is one with a feeder to each floor (Fig. 248), whereby flexibility of control and good voltage regula-

tion are assured. The method of Fig. 249, one feeder serving three or more floors, is probably most often used. It costs somewhat less than the feeder-per-floor method but does not provide equal flexibility of control or quite so good voltage regulation. The feeder and main arrangement of Fig. 250 will also give good results if the main connecting the distribution boxes is made of the same size of wire throughout, thus avoiding the installation of fuses in series (see a discussion of this matter, as applied to the mains connecting a number of panel boxes on the same floor, which is given in a following paragraph). Sometimes a single main is made to serve all the panel boxes in a building, as in Fig. 251, but in general this places "too many eggs in one basket" and results in inflexible control. Any particular case must be decided on the basis of cost and merit.

396. High-voltage, Vertical-distribution Systems.—For very high office buildings the low-voltage, feeder-and-main distribution systems discussed in Secs. **394** and **395** are uneconomical owing to the excessive amount of copper required for distributing the large amount of current over such long distances. For this class of buildings a high-voltage, vertical-distribution system has been developed and is rapidly growing in favor. In this system the high-voltage distribution feeders are carried up through the building through a vertical riser shaft. These high-voltage feeders supply banks of step-down transformers located at different floor levels throughout the building. From the secondary side of the various transformer banks the power is distributed at low voltage to the distribution panels supplying the different sections of the building.

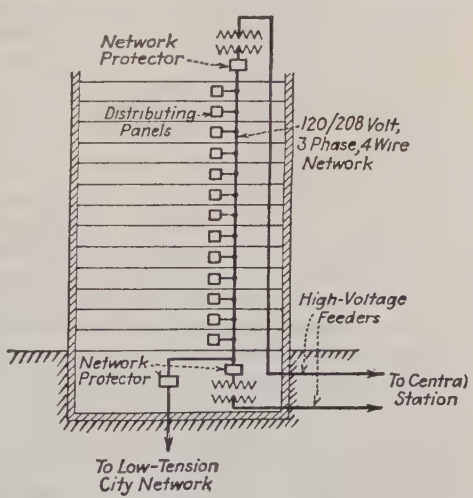


FIG. 252.—High-voltage vertical-distribution system.

Two different types of high-voltage vertical-distribution systems are illustrated in Figs. 252 and 253. In the system of Fig. 252 the building is supplied from two banks of transformers, one bank located in the basement and the other bank located on the top floor. These two banks of transformers feed into the opposite ends of a low-voltage secondary main which extends vertically through the entire height of the building.

The distribution panels on the different floors are supplied from this low-voltage main.

In the system of Fig. 253 the building is divided vertically into sections with one or more banks of transformers supplying each section. High-voltage feeders are carried up the building to supply the banks of transformers T_1, T_2, T_3, and T_4 located at the different levels. The secondary side of the transformers in each section is connected to a common low-tension network bus. From this bus the power is distributed to the various distribution panels in that section by means of a low-tension, feeder-and-main system similar to those described in Secs. **394** and **395**.

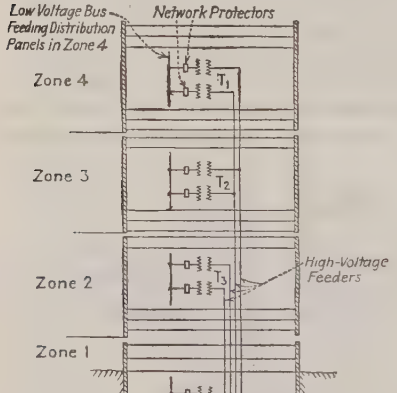


FIG. 253.—High-voltage vertical-distribution system.

In the high-voltage, vertical-distribution systems, protection is provided by means of automatic network protectors in the secondaries of each bank of transformers. In case of trouble causing the low-voltage network to feed back into any one bank of transformers, the network protector will disconnect the transformers from the low-voltage bus. Upon the restoration of proper voltage the network protector will automatically reconnect the transformers to the low-voltage bus.

397. Distribution to Panel Boxes on Floors.—Often in buildings covering a small area one panel box per floor for general lighting is sufficient. Figure 248, floors IV and V, shows an arrangement of mains from the distributing box to the panel boxes that may be used where the distributing box is located at about the center of the building. The layout on floor V is the best because with it trouble is localized, and very uniform voltage at panel boxes is assured. Where, as shown in V, subdivided mains are used the conduit for them will be small and can be readily installed within the floors. The method of IV is cheaper than that of V, but the disadvantage is that fuses are required in series in the mains at each point where the wire size changes. The mains can be made the same size throughout at increased cost, and fuses thereby avoided (see information on mains and tapered mains in Div. 3 of this book).

Where the feeder to a floor rises at one side of the building the mains from the distributing box to the panel boxes may be arranged as in Fig. 249, floors IV, V, and VI. The layout of VI is objectionable because

there must be a fuse in series with the main in every panel box. By using two sizes of wire in V instead of four, the number of series fuses is reduced to two. The best arrangement is that of IV, because with it there are no series fuses, and troubles are localized.

398. Shop Wiring Design.—The design of the wiring system between the generating station and the shop buildings of an industrial plant that generates its own power is treated in another section, and a general comparison of the distribution methods that may be involved is there given. The wiring for the lighting circuits within the shop is laid out on the same general basis as for other buildings as herein outlined. At least one convenience outlet should be installed in each bay in both manufacturing and storage areas. The lighting, feeder, main distribution-center, and panel-box layouts are about the same as for other buildings. For groups of motors, circuits independent of the lighting circuits should be provided unless the motors are very small. These independent circuits should extend preferably from the generating station or at least from the entrance through the building to points wherever there are motors.

In general, the factors affecting the design of interior feeder and main layouts for power circuits are the same as given in Sec. **386.** Often in a one-story shop or on each of the floors of a multistory shop the best method of serving the motors is to carry a single main the entire length of the shop. The motors can then, through fuses and switches, be connected to this main. A single main on each floor suffices for a narrow shop. Where the shop is wide, several parallel mains so located that no motor is very far from some one of them may be installed. Often a ring main running around just inside the shop walls (see Fig. 18, Sec. **24,** Division 3) provides a good arrangement. The branches from the main can be carried down the walls and under the floor to the motors. In installations which require frequent rearrangement of the machinery, the bus-way systems in Secs. **192** and **193** provide a flexible distribution system which will eliminate excessive expenses in the reconstruction of the wiring system. In a shop of several stories, unless the motor load is very small, it is a good plan to run separate power mains from the entrance to the building to each floor, but any of the feeder and main arrangements shown for lighting circuits in Figs. 248 to 251 can be used. However the layouts for power conductors should be, and usually are. much more simple than those for lighting conductors. A simple arrangement is usually possible because a close voltage regulation is not so important with power as with lighting circuits.

399. Load-center Power Distribution for Industrial Buildings.—Load-center power distribution has two distinctive features which set it apart from other methods of delivering electric energy to points of use within a plant or building. They are

1. Power is received and distributed at high voltage (2.4 to 13.2 kv.) to unit substations located close to the centers of electrical load. Here it

is stepped down to utilization voltages (600 volts or less) and delivered by short secondary feeders to the points of use.

2. Where the total plant load cannot be met by a single small substation, 1,000 kva. or less, two or more load-center substations are used, rather than a single substation at the point of incoming supply.

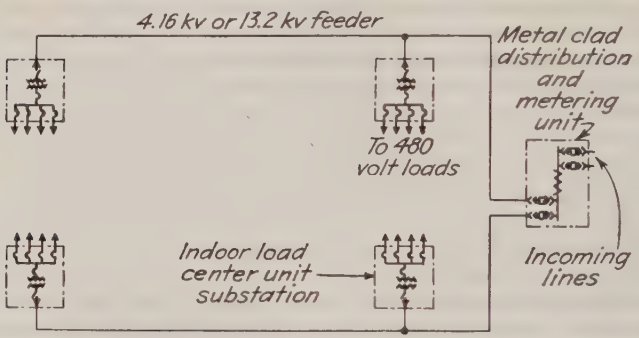


FIG. 253A.—Load-center distribution, single radial circuit.

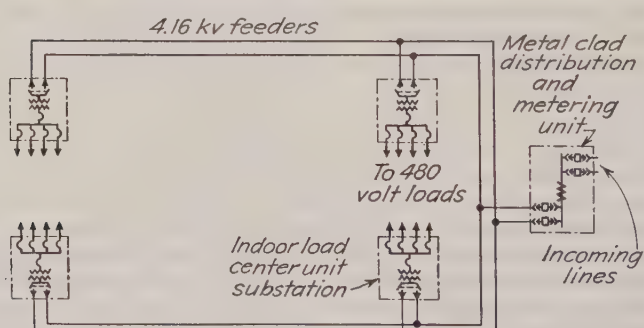


FIG. 253B.—Load-center distribution, primary selective circuit.

A load-center system can be laid out in any one of four basic circuit arrangements, as follows:

1. The simple radial arrangement (Fig. 253*A*).
2. The primary selective arrangement (Fig. 253*B*).
3. The secondary selective arrangement (Fig. 253*C*).
4. The secondary network arrangement (Fig. 253*D*).

These four arrangements (or any combination of the four) offer various degrees of service reliability with corresponding variations in first cost. Because of its low cost and because of the rarity of primary-feeder or transformer failure, the simple radial circuit arrangement finds application in many plants. When the plant is supplied by two power lines, the

primary selective arrangement will provide reliable service in areas where long service outages resulting from primary-feeder failures cannot be tolerated but where the short outage involved in switching from the faulty feeder to the healthy one would not be particularly bothersome. The secondary selective arrangement is designed for plants in which provision must be made to supply all load busses with some power to keep

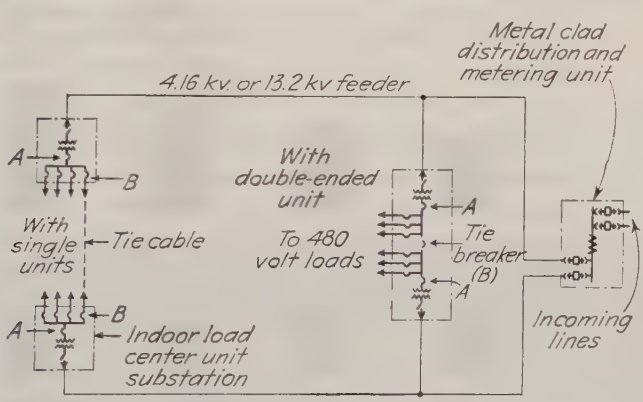


FIG. 253C.—Load-center distribution, secondary selective circuit.

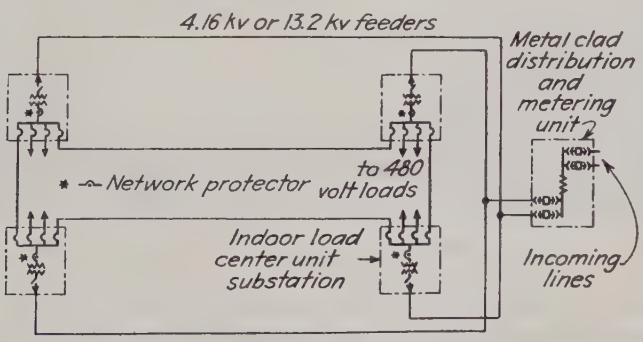
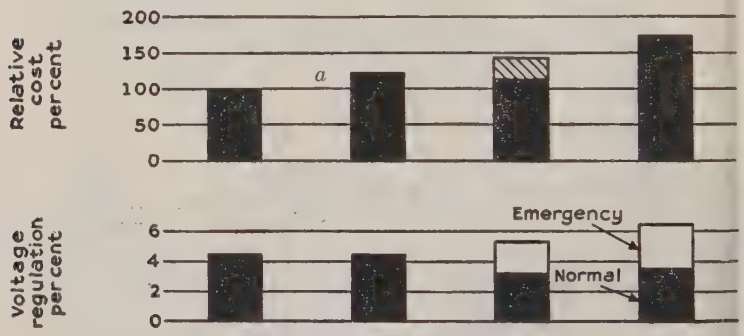


FIG. 253D.—Load-center distribution, network circuit.

important loads running in the event of either a primary-feeder or a transformer failure. The secondary network is particularly well suited to continuous-process plants, hospitals, etc., where even the short outages of the secondary selective arrangement are not acceptable. Because of its high cost and complexity, it does not lend itself to general use.

400. The relative performance characteristics of the four basic circuit arrangements for load-center distribution are summarized below:

	Simple radial	Primary selective	Secondary selective	Secondary network
Number of load-center units	5	5	2–4	6
Unit-transformer kva	600	600	600	600
Total transformer kva	3,000	3,000	4,800	3,600
Firm load capacity	3,000	3,000	3,000	3,000



Intangible Characteristic[b]				
Safety	A	C[a]	A	B
Service reliability	D	C	B	A
Ease of operation	A	B	B	B
Maintenance	A	B	B	C

[a] These values for disconnecting switches as transfer means. When adequate-interrupting-capacity power circuit breakers are used, the cost is increased, and the arrangement rates an A in safety.

[b] A is best.

401. Load-center unit substations consist of compact, full-safety-enclosed, factory-built combinations of high-voltage switching and protective equipment, load-center step-down transformer, and low-voltage feeder switching and protective equipment. The load-center transformers are of either the noninflammable, nonexplosive, liquid-immersed, self-cooled type or the self-air-cooled type (dry type), so that the transformers may be installed in the open throughout the plant without the use of transformer vaults. In large plants the lighting load may be supplied from unit substations separate from the unit power substations. A simpler arrangement, applicable to most plants, is to supply the lights and miscellaneous 120-volt loads from small step-down transformers supplied from the low-voltage feeders of the power-supply system.

The load-center unit substations may be located as close as possible to the center of the load they supply in any one of the following locations:

1. Along the walls near the working areas.
2. On balconies above the load centers.
3. In basement below the production floor.
4. Outside the building adjacent to load area.
5. On building roof or rafters.
6. On elevated platforms close to the loads.

FARM WIRING

402. Farm Wiring.—The use of electric power on the farm is continually increasing. In order that the farm electrical system may be adequate and give the best results in expenditure of money and satisfactory service, it is essential that the system be properly and wisely planned,

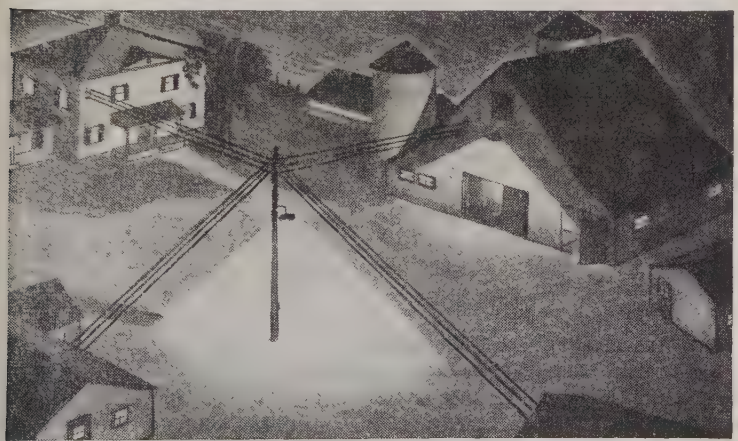


FIG. 253*E*.—Power pole for farm-building distribution feeders. (*General Electric Co.*)

that good materials and equipment be employed throughout, and that good workmanship be employed in its installation. In most cases the best installation will be achieved by the use of a power pole, as shown in Fig. 253*E*. The power pole will be the central distribution point of the electrical system. The power company will run its supply lines from its main pole line to the power pole of the farm and down the pole to their meter. From the power pole, the consumer will distribute the electric power by overhead lines to the different buildings. In rare instances, it may not be possible to erect a power pole. In this case, the power lines from the public utility will terminate at a building, probably the farmhouse. The meter will then be installed at this point. This

method introduces some complications and is recommended only where the erection of the power pole is very difficult or impossible.

The first step in planning the farm electric system is to determine the power demands for each building. The diversity of farm work makes it impossible to set down definite load requirements to fit all farms. Every kind of farming has its own needs insofar as power, machinery, and appliances are concerned. However, a number of wiring requirements are fundamental to the various farm buildings. No matter where the farm is located or how the buildings are constructed, certain minimum standards of wiring must be followed to obtain satisfactory electrical service. The following sections specify proper wiring for average conditions. They take into consideration the correct number of outlets, the proper switching, modern lighting, and adequate wire sizes for the machinery and appliances that are normally used in specific farm buildings. They are intended as a basic guide. If more equipment is to be installed than is included in these specifications or if the farming operations are of a special nature, the specifications must be varied to suit the special needs.

403. Range of Farm-building Loads

Building	Estimated Load, Kw.
House	7–12
Dairy barn	8–16
Milkhouse	2– 6
Poultry house	1.5– 8
Each brooder	1.2
Poultry cleaning, dressing, waxer, etc	5
Workshop and machine shed, including welder	6.5
Pumphouse	Demand depending on depth of well
Granary, hog house, corncrib, sheep shed	5–11

404. Specifications for Dairy Barn.

Lights.—In back of cows one lighting outlet every 12 ft.; in front of cows a lighting outlet approximately every 20 ft. One or two lights on top of the silo, so installed that they will light silo and chute. Only general illumination is needed in the haymow. Flood lights above the hay line on opposite walls of the barn will therefore give the required lighting.

Convenience outlets should be placed approximately 15 ft. apart in a row back of the cows. Where cows face in, outlets should be on the wall, up high enough so that cattle cannot come in contact with them. Where cows face out, outlets should be suspended from the ceiling on heavy-duty cords. They must be hung so that they can be reached easily yet high enough not to obstruct traffic.

In open spaces a convenience outlet should be installed for each 600 sq. ft. area.

Switches.—It is best to install separate switches for each row of lights in the barn. In small barns, however, all lights in back of the cows may be on one switch. When two or more entrances are used frequently,

at least one row of lights should be controlled by three-way switches. The switch for the lights in the haymow should be mounted at a convenient location on the barn floor and should also be equipped with a pilot light. To have a visible indication when the light is burning in the silo, a switch with pilot light is recommended mounted at the entrance of the silo chute.

Circuits.—The service-entrance panel for the barn must be adequate to take care of the load. Since some of the equipment needs special circuits, it is important to have an entrance panel of the proper capacity.

The following number of circuits is recommended as a minimum. However, additional equipment or change in barn layout may make it necessary to deviate from this recommendation.

Lights	2 circuits (depending on size of barn)
Milking machine	1 circuit (230 volts)
Feed grinder	1 circuit (230 volts)
Utility motor	1 circuit (230 volts)
Convenience outlets	1 circuit (depending on size of barn)
Fans	1 or more (depending on size of barn)
Hay drier	1 circuit (230 volts)

405. Specifications for Milkhouse.

Lights.—In most cases a center light will be sufficient except where the milkhouse is unusually large. Then additional lights will be necessary over the work areas, especially where the utensils are washed.

Convenience Outlets.—At least one convenience outlet for general use should be installed at convenient location in the milkhouse. It is advisable to put this outlet on a heavy-duty circuit of No. 10 A.w.g. wire.

Switches.—All lights should be controlled by a switch at the entrance.

Circuits.—Where it is connected to the barn, the circuits for the milkhouse may be included in the barn entrance panel.

When the milkhouse is separate, a special entrance panel must be installed.

The following circuits are recommended as a minimum:

Lights and outlets	1 circuit
Milk cooler	1 circuit
Water heater	1 circuit (230 volts)
Sterilizer	1 circuit (230 volts)
Ventilating fan	1 circuit (if fan is small, it may be connected to light and outlet circuit)

406. Specifications for Workshop, Garage, and Machine Shed.—Frequently the workshop, garage, and machine shed are one building, subdivided to serve all three purposes. The wiring for this building must therefore be arranged to suit this special condition.

Lights:

Workshop.—A well-lighted workshop is absolutely necessary for doing good work. Two types of lighting are needed—general lighting for the

entire workshop and localized lighting over the workbench and near permanently located equipment.

For this reason, a ceiling light must be installed for every 200 ft. of floor area, at least one and possibly two lights over the workbench, and conveniently located lights over the stationary tools such as drill press, plane, forge, saw, etc.

Garage.—One light over the front of the cars and another one at the rear will permit making minor repairs to the car and other equipment.

Machine Shed.—One or two ceiling lights, depending on the size of the shed, give sufficient general illumination. Lights must be properly placed for best results.

Convenience Outlets:

Workshop.—Convenience outlets in the workshop have to serve many different purposes. There must be a sufficient number, properly located, to facilitate the work. Install at least two convenience outlets over the workbench and other outlets throughout the workshop for the connection of the electric tools. A heavy-duty outlet must be installed for the portable welder.

Garage.—A convenience outlet at the rear wall of the garage permits the use of portable tools, battery charger, and extension lights.

Machine Shed.—Since the welder may frequently be used in the machine shed, a heavy-duty outlet should be provided. Other convenience outlets should be considered for the connection of portable tools such as drills and soldering irons.

Switches:

Workshop.—The ceiling lights in the workshop should be controlled by a single-pole switch near the entrance. The lights over the workbench and fixed equipment can be controlled by pull-chain switches inside the fixture.

Garage.—A single-pole switch near the entrance of the garage is needed for the control of the ceiling lights.

Machine Shed.—The same type of switch control should be used here as in the garage.

Circuits.—As in the barn and milkhouse, the service-entrance panel for the workshop must have the correct capacity for the load. Since all the equipment will never be used at one and the same time, a reasonable diversity factor may be taken into consideration.

The number of circuits depends, of course, on the equipment and machinery installed. However, the following minimum should be carefully considered:

Lights	1 circuit
Convenience outlet	1 circuit
Wood saw and planer	1 circuit (No. 12 wire)
Portable welder	1 circuit (230 volts)

407. Specification for Poultry House.

Lights.—Lighting in the poultry house serves to increase egg production in addition to providing light for seeing. One light should be installed for each 200 sq. ft. of floor area, but, if pens are smaller than 200 sq. ft., at least one light per pen must be provided for.

The same general lighting arrangement should also be kept in the poultry house workroom with additional local lighting for egg cleaning, grading, poultry scalding, waxing, etc.

Since ultraviolet light promotes healthier stronger birds, sunlamps should be installed over feeding troughs.

It is also recommended that at least one germicidal fixture for each 100 sq. ft. of floor area of laying pens be installed. These lamps should be on a separate switch so that they can be turned off when someone is working in the pen.

Convenience Outlets.—In the laying pens, to connect the water warmer, at least one convenience outlet should be installed for every 200 sq. ft. of floor area. The outlets are best located at the ceiling and should be equipped with the twist-lock type of receptacle.

In the brooder house, the same arrangement of receptacles is recommended to serve brooders and water warmers. In the workroom, convenience outlets must be installed for the egg-cleaner, candler, grader, poultry scalder, and waxer.

The feed-grinder and feed-mixer motors have to have special heavy-duty outlets on a 230-volt circuit.

Switches.—Lights for all the laying pens should be connected to a regular switch as well as to an automatic time switch. The time switch will make morning lights to control egg production possible.

The ceiling lights in the workroom should be on a separate switch from the lights in the laying pens. The local lighting over the work areas can be controlled by wall switches or by pull-chain switches in the fixtures. Germicidal lamps, being on at all times, do not need a switch.

Circuits.—The following circuits are recommended for the poultry house as a minimum:

Lights	1 circuit (depending on size of poultry house)
Ultraviolet lamps	1 circuit (depending on size of poultry house)
Germicidal lamps	1 circuit (depending on size of poultry house)
Convenience outlets	1 circuit
Brooder outlets	1 circuit each brooder
Feed mixer	1 circuit (230 volts)
Feeder grinder	1 circuit (230 volts)

408. Specifications for Hog House or Sheep Shed.—For general illumination, a lighting outlet every 20 ft. along the passageways should be sufficient. These lights should be controlled by a single-pole switch near the entrance. Convenience outlets are needed in the farrowing pen

for the connection of the pig brooders. This outlet should be about 3 ft. above the floor and in a corner of the pen.

409. Specifications for Granary and Corncrib.—Lights over the center of the drive spaced 20 ft. apart are needed in the granary and corn crib. These lights should be controlled with a switch at the entrance. Upstairs, a light is needed for approximately every 200 sq. ft. of storage area with a switch and pilot light installed downstairs near the stairs. At least one power outlet is needed downstairs for the connection of the grain elevator.

410. Specifications for Farmyard.—In the farmyard, electricity serves many important functions. Lights properly switched help in performing the evening chores. Outlets are needed throughout the yard for connection of the portable utility motor. Therefore, a plan for the wiring for a farm should include proper lighting and outlets outdoors. In general, the following simple rules will be sufficient:

Lights.—Install at least three lights in the yard—one at the house, one at the barn, and one at the workshop or garage. They should be at least 15 ft. above the ground to allow a wide spread of light.

Outlets.—Heavy-duty, weatherproof outlets are needed for the connection of the utility motor. One should be mounted at the barn near the silo and others at all places where farm chores will employ the utility motor. If the pumphouse is located adjacent to the yard, a separate circuit to the pump motor should be provided.

Switches.—To make it possible to turn the lights on or off from several different points, three- and four-way switches must be installed. A switch at the house, one at the barn, and a third one at another convenient place are recommended for maximum efficiency.

411. Planning the Farm Wiring System.—After the required loads have been determined, the wiring system may be planned. The system will be considered in three parts: (1) the power pole, (2) distribution feeders, and (3) interior wiring of each building.

412. Power Pole.—To be of best service, the power pole (Fig. 253*E*) should be erected in a spot as central to the different electrical loads as possible. Often this is somewhere halfway between the house and the barn.

Normally a main switch and fuse or circuit breaker will not be required. However, it is good practice to install one on the power pole. A rain-tight main switch on the power pole will permit the power to be cut off from one centrally located point. A feeder of the required current-carrying capacity for the entire farm load must be run from the meter to the main switch if used and up to the top of the pole. The distribution feeders will be tapped off from this main feeder at the top of the pole. Regardless of the present load, the main feeder should not be less than No. 2 wire.

The entire wiring system must be grounded at the power pole. This is

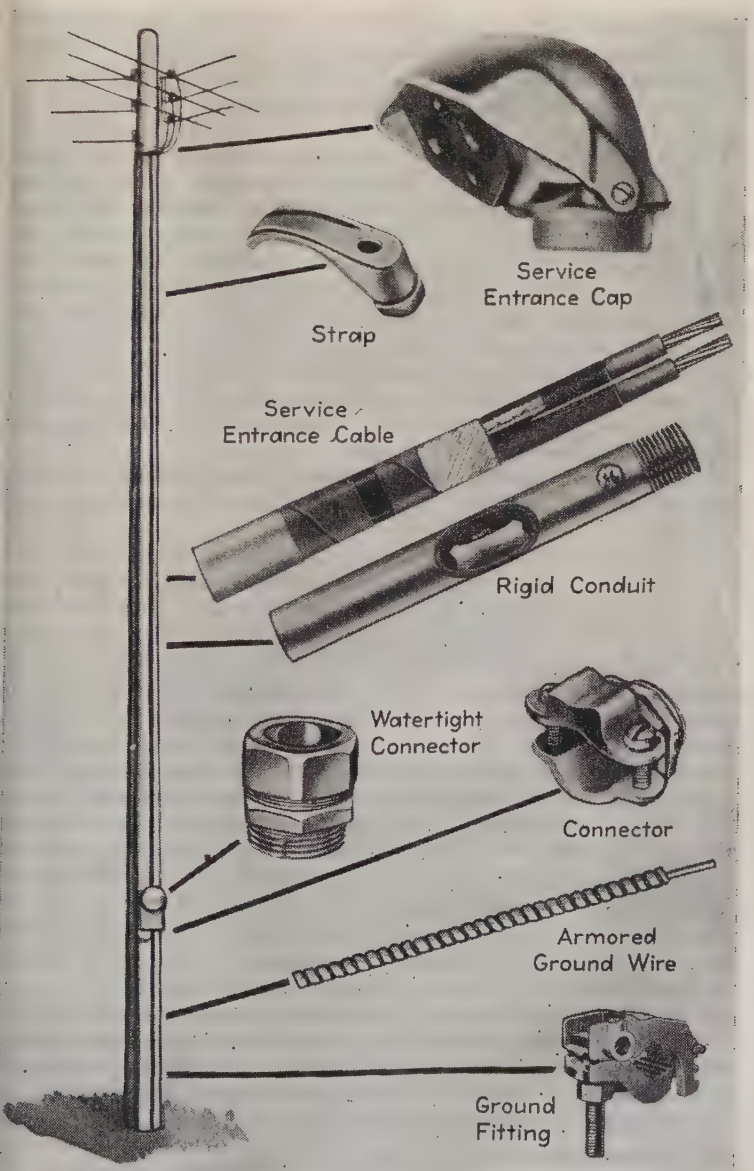


FIG. 253*F*.—Power-pole equipment installation. (*General Electric Co.*)

usually done with driven ground rods (refer to Sec. **255**). The groundin is a very important safety measure, and the advice of the power supplie should be obtained with respect to the proper method to employ.

A power-pole installation employing good equipment is shown i Fig. 253*F*.

413. Distribution Feeders.—An individual feeder from the powe pole to each building is best. However, the location of the building may make it necessary to connect one building from another. Simi larly, to buildings with very small electrical loads, it may be equally goo and less expensive to extend feeders from a near-by building. Thi feeder, when tapped on the outside of the building, without going throug the service-entrance panel of the first building, permits additional loa and future extensions in the second building. Additional wiring can b installed without affecting the load in the first building. No matter ho small the load in any one building may be, this method is recommended.

The length of the feeder from pole to building and the electrical loa inside determine the size of the feeder.

For mechanical strength, no feeder can be smaller than No. 10 wir when the span is 50 ft. or less. A span longer than 50 ft. needs wire No. or larger.

The actual size of the feeder can be calculated by the methods give in Div. 3. The voltage drop for any feeder should not exceed 2 per cen

If one or more buildings are connected from another, feeder sizes fro the power pole to the first building must be increased. Use 100 per cen of the building having the largest load plus 50 per cent of the combine load of the other buildings. No one can foretell how quickly the use c electricity will be increased. It is therefore recommended that feede at least one size larger than the load figures indicate should be used.

It is recommended that all feeders shall be three-wire 115/230 volt However, for a small load in a particular building, a two-wire 115-vo feeder may be satisfactory. Feeders to buildings having a load of 3,45 watts or more or to buildings having a motor of ½ hp. must be three-wir

414. Wiring of Buildings.—Normally the power-distribution feeder fo the power pole to a building is secured to the building with an insulato bracket (see Div. 8). Brackets should be mounted high enough so tha the power feeders are never suspended lower than 18 ft. over driveway for clearance of loaded wagons, and 10 ft. over footwalks.

From the insulator bracket service entrance, conductors are run dow the side of the building to a point where they enter the building and co nect to the service-entrance panel. Service-entrance cable is recom mended for this purpose. This cable with its tough nonmetallic out covering protects cattle from coming in contact with metallic parts of th wiring system.

If there are not more than six circuits in a building, a main circu breaker or main fuse is not required. The table in Sec. **415** will give a

idea of the size of service-entrance panels required (refer to Secs. **260** to **269** for information on service entrances).

It is recommended that armored cable or nonmetallic-sheathed cable be employed for the interior wiring of the buildings (refer to preceding sections of this division for information on wiring, and refer to Secs. **404** to **409** of this division for information on requirements for lights, convenience outlets, switches, and circuits).

At each building the wiring system must be grounded. This is in addition to the ground at the power pole. Grounds must be established at each point of entrance to each building, and, if possible, all these grounds should be tied together on driven grounds. Also, for added safety, the farm water system should be tied at each building to the driven ground for that building. This is important. A well-grounded wiring system adds to the safety of the entire installation.

415. Service-entrance Requirements.

Building	Average Service Entrance Required, Amp.
House	60–100
Barn	60–150
Milkhouse	20– 30
Poultry house	30– 60
Pumphouse	30, depending on depth of well
Workshop and machine shed	30–100
Wagon shed, corncrib, miscellaneous building	30–100

WIRING FINISHED BUILDINGS

416. Information on Wiring Old Buildings.—For detailed information concerning this subject, see the author's book, "Wiring of Finished Buildings."

417. In laying out old-house wiring installations, the first things to be considered are the location of the meter and the panel board, and the point where the wires are to enter. The meter should generally be located in either the kitchen, back hall, or cellar or outside the house. In the smaller houses, the panel board should be located near the meter, and in the larger houses, where there are a number of branch circuits, at the central point of distribution, *i.e.*, at some point on the second floor, preferably the hall. The point of entry should be located with reference to the accessibility of the service connection.

418. Typical Wiring Plan of an Old Building.—Figure 254 shows the routes taken by the wires, to chandeliers and switches, within walls and under floors. The point of entry for the mains in this case is the kitchen, on the outer wall of which are located the main switch, the fuse block, and the meter. Double-pole switches are shown, as they are required in certain cities in installations where combination gas and electric fixtures are used. Single-pole switches installed in accordance with National Electrical Code rules are practically as good for the average installation.

The methods of carrying conductors to single-pole switches will be obvious from a study of the illustration.

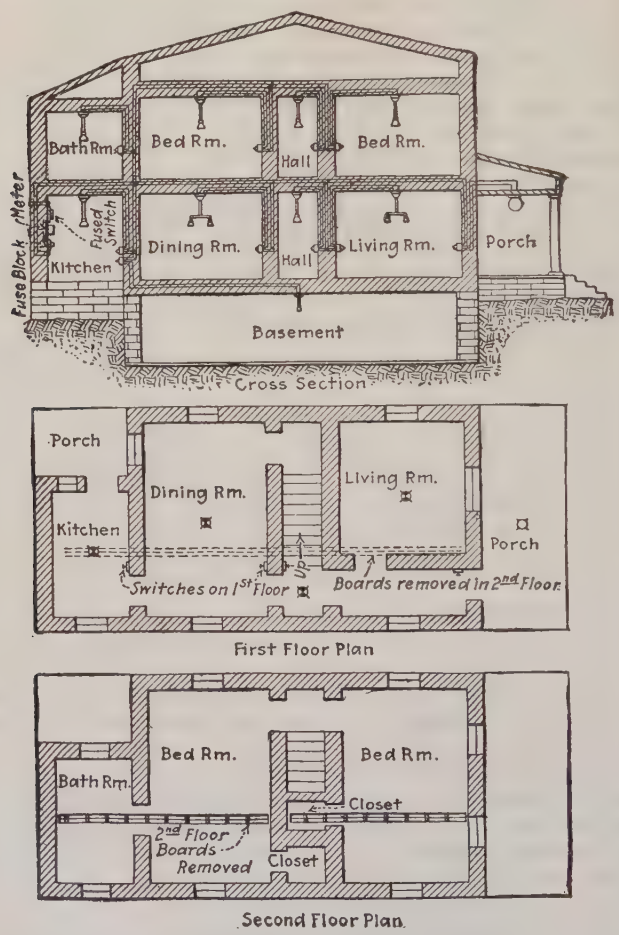


FIG. 254.—Wiring of a five-room house.

The dotted lines show the flooring boards taken up on the second floo and the fixture and switch locations on the first floor are indicated. T switch locations are within easy fishing distance.

The flooring boards are removed on the second floor in such locatio as to pass under one partition only, and with regard to accessibility of t outlet and switch openings below.

In many houses of the type shown, the space between roof and second floor ceiling is sealed, in which case a hole is cut in the ceiling of a closet, and the opening is provided with a trap door.

419. Special Tools Used in Wiring Old Buildings (see Fig. 255). 1. **Pipe Extension Bit.**—Used to drill, up from the cellar or down from the third floor, through crosspieces or headers in a partition where it is impossible to get over or under them. A 2-in. bit is used, making a hole large enough to take four pieces of flexible tubing. Cases are known where boring has been done from the cellar to the third floor successfully,

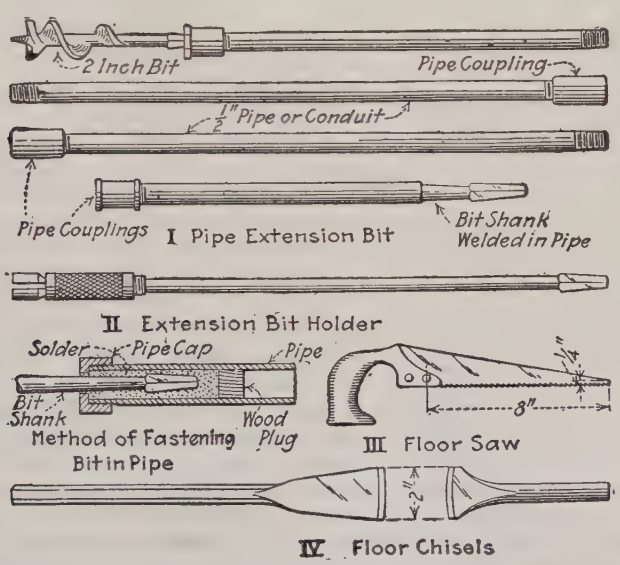


FIG. 255.—Tools used in wiring old buildings.

although the necessity for this is very rare. Figure 256 illustrates the application of this device. A bit brace can be used for turning it, or if the space is restricted a pipe wrench can be used.

2. **Floor Saw.**—Used in removing flooring boards, made short enough so that it cannot be pushed through the plaster of the ceiling below. The blade is ¼ in. wide at the point and approximately 8 in. long with a handle similar to that of a keyhole saw.

3. **Floor Chisels.**—Used in removing the flooring boards. The chisels are from 12 to 24 in. long and 2 in. wide at the point.

4. **Extension-bit Holder.**—Used in a bit brace for drilling holes in joist. They are 2 to 3 ft. long, and enable the wireman to drill holes in a recess or in places where a long bit would be needed. By coupling two of the holders together, the wireman can drill circuit holes in the joist while

standing, which renders the work much easier, where there are a numbe of holes to be drilled.

5. **Mouse.**—Used in locating crosspieces and finding clear spaces i partitions. It is made up of a length of twine with a piece of lead o other heavy material on its end.

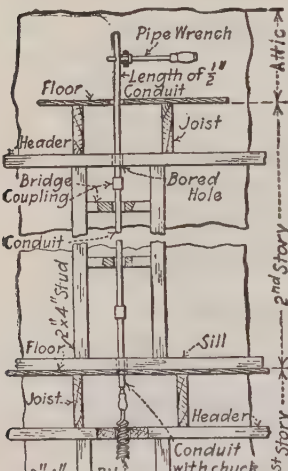


Fig. 256.—Illustrating use of the pipe-extension bit.

6. **Snake.**—Used in fishing wires throug partitions or under floors; made of rectan gular or round steel wire.

420. Removing Flooring Boards.—Firs a slot must be made in the seam betwee flooring boards of sufficient size to enabl the floor-saw blade (Fig. 255) to be inserte This is best done with a sharp, narro chisel having a ⅝-in. blade. Then the sa blade is inserted, and the tongue at th junction of the flooring boards is sawed o the full length of board to be remove The wireman can tell when he reaches th joist at which he wishes to end his cut. A this point the chisel blade is placed with th flat part across the board at edge of th joist, and another small slot made. The the board is sawed off even with the joi and can be easily removed with a floor chis (Fig. 255). When the board is replaced, cleat is nailed to the joist (Fig. 257) for th board to rest on, and then the board nailed down, or better yet, screwed down, so that if it is necessary get at the wires again it can be done with little trouble. When fastenin down the flooring, two nails or screws should be put in each joist. Whe only one nail is used, the board is apt to squeak when walked over. To ensure a substantial job, any floor board that is removed should be long enough to bridge at least two joists.

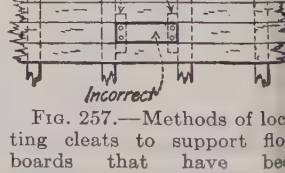


Fig. 257.—Methods of loc ting cleats to support flo boards that have be removed.

421. Fishing to Center Outlets.—A great deal depends on the layout of the house. Almost invariably the joists are run parallel to the street. If the house is one with a side or center hall on the second floor, the circuits can be run the length of the hall, necessitating the removal of two boards for that distance. Wires can then be fished from t center of the room by cutting a small hole at the chandelier location or b cutting a pocket in the floor directly above the location of the outlet. If

is necessary to take up the boards in the floor at some distance from the partitions, another pocket will have to be taken up close to the partition in order to drop the switch loops, and to go through to the other side. This is necessary when the hall is in the center, with the rooms to be wired on each side.

If, as is the case with some of the smaller houses, there is no hall on the second floor, and the rooms are directly in the rear of each other, the boards can be taken up through the doorways, and the wires dropped to the switches, outlets, and to the panel board in the kitchen very readily (see Fig. 254). Where there are hardwood floors, the wires must be fished from the center of the room to a closet or to a point where the baseboard can be removed, so as to get into a partition going either up or down. In a great many cases it is necessary to drop to the cellar and then come up again in another location for the switch loop. Where this is necessary, the most convenient place for the panel board is in the cellar.

422. When plaster-of-paris molding or centerpieces are to be drilled, the Syracuse bit is the best. In many cases it is necessary first to saw off the lower portion of the center decoration to provide a flat surface to front the drill. Use very little pressure and have the drill very sharp.

423. Wiring for Switch Loops.—In a great many cases the bringing out of the switch loops at outlets at a proper distance from the floor is the most difficult part of wiring old houses, on account of the crosspieces or bridges sometimes found in partitions. The method to be used must be determined by the wireman on the job, according to the conditions found. Following are some of the methods used:

First, with his mouse, he finds if the runway is clear; if so, the rest is easy. But, if he finds there are crosspieces, he locates their position by measurements with the mouse, and marks the location on the wall. If the crosspieces are above the proper positions for the switch, he will probably use one of the following methods of getting around it:

1. Remove the doorstop strip from the frame of the doorway (Fig. 258), bore through on each side of the crosspiece, cut a recess in the inside of the frame, and then fish the wires around.

2. If on the second floor and there is no partition directly above, the wireman can use a pipe extension bit (Fig. 255, I), drilling one hole large enough to fish the switch loop through.

3. If the crosspiece is not too far above the proposed location of the switch, holes can be drilled on a slant from switch opening.

4. Remove the wallpaper directly over the crosspiece, which can easily be done, especially in an old house where there are several thicknesses of paper, either dry or by dampening it. This can be done by cutting an X through the paper at the point over which the opening is to be made, and bending the paper back, but taking care not to bend it enough to crease it. Then cut a hole smaller than the paper removed and bore holes or

cut away the crosspiece enough so that the wires will pass. If there is figure or flower where the crosspiece is located, it can be cut out with sharp knife, and, after the hole is plastered up with plaster of paris, th paper can be replaced very neatly. A careful man usually performs th operation very successfully.

5. Sometimes a wireman will attempt to remove these crosspiece when he can get at them from above, by putting a piece of pipe dow between the partition and hitting it with a heavy hammer. This metho

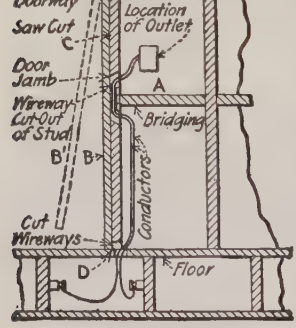


FIG. 258.—Carrying wires around a bridge.

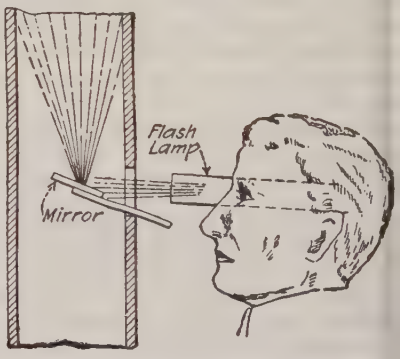


FIG. 259.—Examining partition interior

is apt to cause damage to the plaster by bulging or breaking it out and i not recommended.

6. When a switch must be located on a brick wall, it is necessary t run wires in rigid or flexible steel conduit. The wall must be channeled and the conductor buried in it, and the groove replastered. At the poin where the metal terminates under the floor a suitable outlet fitting mus be provided.

424. Examining Partition Interiors.—With a pocket flashlight and little mirror the interior of a wall or partition which would ordinarily b inaccessible can be inspected (Fig. 259). The mirror is introduced i the outlet hole, and the flashlight and eye are held behind it as illus trated. The mirror reflects the light of the lamp onto the place to b illuminated, at the same time reflecting the image back to the eye.

DIVISION 10

ELECTRIC LIGHTING

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PRINCIPLES AND UNITS

1. Explanation of Light.—Light ("Standard Handbook for Electrical Engineers") may be defined as radiant energy of those wave lengths to which the human eye is sensitive. Figure 1 shows the complete ether spectrum of electromagnetic waves, which travel through space at the velocity of approximately 186,000 miles per second. The longer waves are the ones used in radio communication; the shortest ones are the X rays and cosmic rays. The waves to which the eye is sensitive are those near the middle of the spectrum, of a length of about 0.0004

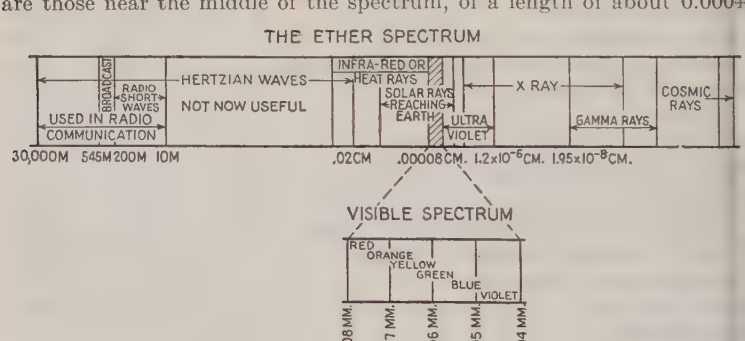


FIG. 1.—The ether spectrum.

to 0.0008 mm. An enlarged section of this part of the spectrum is shown in the figure.

The effect of light upon the eye gives us the sensation of sight. The impression of color depends upon the wave length of the light falling upon the eye. There are three primary colors of light—red, green, and violet. Violet light has the shortest wave length of the radiant energy to which the eye is sensitive; red the longest; and green an intermediate wave length between that of violet and red. These three colors are called the primary colors, because light of any one of them cannot be produced by combining light of any other colors. Light of any other color than these three can be produced by combining in the proper proportions light of two or all three of the primary colors.

2. Propagation of Light.—Rays of light travel in straight lines unless interfered with by some medium that absorbs or deflects them. Whenever a light wave strikes a different medium than that through which it has been passing, there are three fundamental phenomena that may

occur—absorption, reflection, or refraction. Whenever light waves strike any object, a portion of their energy is absorbed, the amount depending upon the nature of the substance. This absorbed energy is dissipated in the form of heat. The remaining portion of the light may be all transmitted through the substance, all reflected back from the surface, or part transmitted and part reflected, depending upon the nature of the substance and the angle at which the light impinges upon the surface of the object. If the light strikes the object perpendicularly to the surface, it is either transmitted in a straight line through the substance or reflected back from its surface in the same direction in which it impinged upon the surface. If light strikes an object at an angle other than 90 deg. to its surface, then either the light is transmitted through the object but in an altered direction (refraction), or the light is reflected back from the object but in a different direction than that in which it impinged upon the object (reflection). With most objects all three of the phenomena occur, some of the light impinging upon it being absorbed, some transmitted through (refracted), and some reflected back from its surface.

3. Absorption.—Although some of the energy of a ray of light is always absorbed whenever a light ray impinges upon an object, the amount absorbed varies over wide limits, depending upon the nature of the object, the molecular construction, the wave length or color of the incident light, and the angle at which the light strikes the surface. All objects do not absorb light of different wave lengths in the same proportion. It is this phenomenon which accounts for the characteristic color of objects (see Sec. **13**). Since objects do not absorb the same proportion of the incident light of different colors, the amount of light absorbed by an object depends upon the color or wave length of the light impinging upon the object. Tables 4 and 12 give the percentage of incident white light that is absorbed by various types of surfaces.

4. Coefficients (Per Cent) of Absorption of Globes and Shades

Material	Absorption, per cent	Material	Absorption, per cent
Clear glass globes	5–12	Medium opalescent globes	25–40
Light sandblasted globes	10–20	Amber glass	40–60
Alabaster globes	10–20	Heavy opalescent globes	30–60
Canary-colored globes	15–20	Flame-glass globes	30–60
Light-blue alabaster globes	15–25	Enameled glass	60–70
Heavy blue alabaster globes	15–30	White diffuse plastic	65–90
Ribbed glass globes	15–30	Signal-green globes	80–90
Clear plastic globes	20–40	Ruby-glass globes	85–90
Opaline glass globes	15–40	Cobalt-blue globes	90–95
Ground-glass globes	20–30		

5. Absorption is the loss of light flux which occurs when the flux is reflected by a reflecting surface or when it passes through a translucent or so-called transparent material.

Per cent absorption = 100 per cent − per cent reflection − per cent transmitted. (1)

6. Reflection of light (Fig. 2) is the redirecting of light rays by a reflecting surface. Whenever light energy strikes an opaque object or surface, part is absorbed by the surface and part is reflected. Light-colored surfaces reflect (Table 9) a larger part of the light thrown on them than do dark-colored surfaces, whereas dark surfaces absorb a larger part

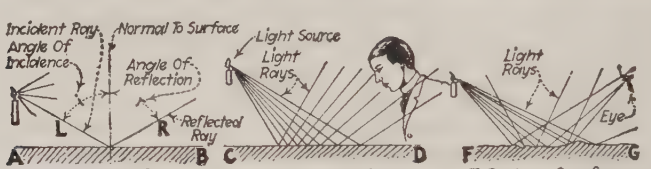


FIG. 2.—Illustrating the reflection of light. (Note that the angle of incidence, i, always equals the angle of reflection, r.)

of the light and black surfaces absorb nearly all the light which reaches them.

NOTE.—Consider first a smooth surface AB (Fig. 2, I), on which a ray of light L falls. This ray will be so reflected in the direction R that the angle i is exactly equal to the angle r. Consider now the effect of a number of rays falling on a smooth surface CD (Fig. 2, II). Each ray will be reflected in such a way that it leaves the surface at the same angle at which it strikes it. The eye if held as shown would perceive only the light reflected into it. Consider now a broken surface such as FG (Fig. 2, III). Each ray of light is reflected from that portion of the surface on which it falls, just as though that point were on a smooth surface. The result is that the light is scattered, and if the surface is irregular enough, the eye placed at any point will receive reflections from many points of the surface. All opaque surfaces except polished surfaces have innumerable minute irregularities like the surface in Fig. 2, III. This alone enables them to be seen.

7. The different kinds of reflection will now be considered. **Regular reflection** is that (Fig. 3, I and 3A, I), wherein the angle of incidence i is equal to the angle of reflection r. This kind of reflection is obtained from mirrored glass, prismatic glass, and polished metal surfaces. **Spread reflection** (Fig. 3, II and 3A, II) is that wherein the maximum intensity of the reflected light follows the law of regular reflection, except that a part of the light is scattered slightly out of this line. Spread reflection is obtained from etched prismatic glass and from rough metallic surfaces. **Diffuse reflection** (Fig. 3, III) is that wherein the maximum intensity of the reflected light is normal to the reflecting surface. This holds over a large range of the angle of incidence. This kind of reflection is usually caused by reflection from particles beneath the surface (see Fig. 3A, III). Diffuse reflection may be obtained from opal glass, porcelain enamel,

paint enamel, and paint finishes commonly used for interior decoration of walls and ceilings.

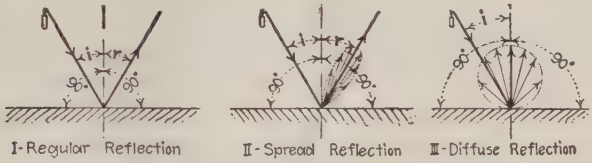


FIG. 3.—Illustrating classifications of reflection.

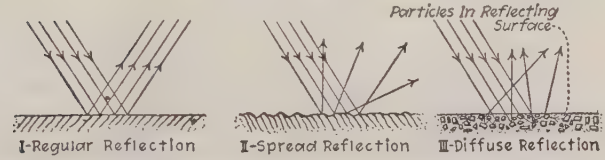


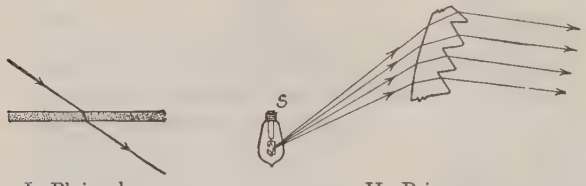
FIG. 3A.—Magnified view of preceding illustration.

8. Reflecting Power of Surfaces.—Different surfaces reflect different percentages of the light falling upon them. The illumination of a small room having poorly reflecting walls may sometimes be improved by changing the wall coverings. If the room is large or if reflectors are used to throw the light downward so that not much light reaches the walls, a change in the wall covering will have little effect on the general illumination.

9. The following table of reflection coefficients (Bell, "Art of Illumination") is useful in showing the relative reflective value of wall coverings in rooms.

Material	Reflection, per cent	Material	Reflection, per cent
Highly polished silver	92	Chrome-yellow paper	62
Optical mirrors silvered on surface	70–85	Yellow wallpaper	40
Highly polished brass	70–75	Light-pink paper	36
Highly polished copper	60–70	Blue wallpaper	25
Highly polished steel	60	Dark-brown paper	13
Speculum metal	60–80	Vermilion paper	12
Polished gold	50–55	Blue-green paper	12
Burnished copper	40–50	Cobalt blue	12
White blotting paper	82	Glossy black paper	5
White cartridge paper	80	Deep chocolate paper	4
Porcelain enamel	70–80	Black cloth	1.2
Ordinary foolscap	70	Black velvet	0.4
Polished aluminum	67	Black, theoretically perfect	0.0

10. Refraction.—Whenever a light ray passes from one medium into another of greater or less density, the direction of the ray is altered. This is called refraction. Refraction may be one of three types: regular, irregular or spread, or diffuse, depending upon the nature of the construction of the substance and the character of its surfaces.



I. Plain glass. II. Prisms.

FIG. 4.—Regular refraction.

Regulator refraction occurs with plain glass or glass prisms as shown in Fig. 4. Light in passing through a substance goes through two refractions, one upon entering the substance and one upon leaving the substance. If the surfaces of the object are parallel, as in a piece of glass (Fig. 4, I) the direction of the light leaving the object is parallel to the direction of the light impinging upon the object. If the surfaces of the object are not parallel, as in the prism of Fig. 4, II, the light leaving the object will not be in a direction parallel to the incident light. A prism may be constructed to refract the light from its different surfaces so that light is not transmitted through the prism but is reflected back as shown in Fig. 5.

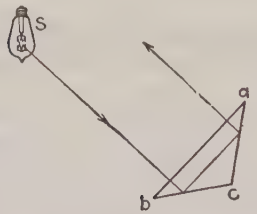


FIG. 5.—Total reflection with prism. (*General Electric Co., Nela Park Engineering Dept.*)

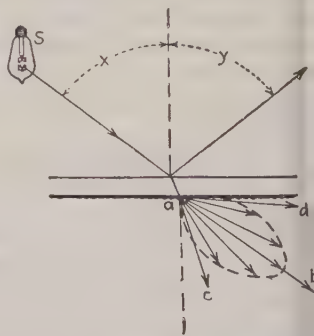


FIG. 6.—Spread refraction with etched glass. (*General Electric Co., Nela Park Engineering Dept.*)

Irregular or spread refraction occurs with light transmitted through glass with a rough surface such as etched or frosted glass, as shown in Fig. 6. Such a surface can be considered as consisting of a great number of very small smooth surfaces making slight angles with each other. The individual rays of light emitting from such a surface are refracted at slightly different angles but all in the same general direction. Thus the

light transmitted through a substance with such a surface is refracted in the same general direction but with the beam spread somewhat from what it would be for regular refraction.

The composition of opal glass is such that it contains a number of minute opaque particles throughout its structure. Light striking such an object travels through the glass until it strikes one of these opaque

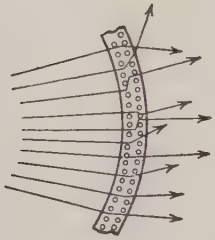


FIG. 7.—Diffuse refraction.

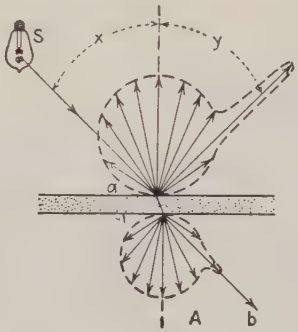


FIG. 8.—Diffuse reflection and refraction with opal glass. (*General Electric Co., Nela Park Engineering Dept.*)

particles, from which it is either reflected back or transmitted through the glass to the other surface. The total beam of light striking the object is thus split up by the innumerable small opaque particles, part being reflected back in all directions, and part being refracted through the glass in all directions. The portion that is transmitted (refracted) through the glass is **diffusely refracted.** An idea of how diffuse refraction takes place can be gained from Fig. 7. In Fig. 8 the diffuse reflection and refraction of a ray of light impinging upon a piece of opal glass is indicated.

11. Most Frequently Used Lighting Units, Abbreviations, Symbols, and the Corresponding Hydraulic Analogies

Photometric quantity	Name of unit	Abbreviation	Symbol	Hydraulic analogy
Light flux	Lumen	Lumen	*F*	Gal. per min.
Luminous intensity	Candle	c.p.	*I*	Pressure in lb. per sq. in.
Illumination	Foot-candle	ft.-c.	*E*	Incident gal. per sq. ft. per min.
Brightness	Lambert	Lambert	*L*	Issuing gal. per sq. ft. per min.

12. Reflection, Transmission, and Absorption Characteristics of Materials

(General Electric Co., Nela Park Engineering Department)

Material	Light reflected			Light transmitted			Light absorbed
	In concentrated beam	In spread beam	Diffused in all directions	In concentrated beam	In spread beam	Diffused in all directions	
Crystal glass:							
Clear	8–10[a]	.....	.....	80–85	.....	.....	5–10
Frosted or pebbled[b]	4–5	5–10	.....	.....	70–85	.....	5–15
Frosted or pebbled[c]	.....	8–12	.....	.....	72–87	.....	5–15
White glass:							
Very light density[b]	4–5[a]	.....	10–20	5–20	.....	50–55	8–12
Very light density[c]	.....	3–4	10–20	.....	5–20	50 55	10–15
Heavy density	4–5[a]	.....	40–70	.....	.....	10–45	10–20
Mirrored glass	82–88	.....	.....	.....	.....	.....	12–18
Polished metal:							
Silver	92	.....	.....	.....	.....	.....	8
Chromium	65	.....	.....	.....	.....	.....	35
Aluminum	62	.....	.....	.....	.....	.....	38
Alzak aluminum	75–85	70–80	.....	.....	.....	.....	15–30
Nickel	55	.....	.....	.....	.....	.....	45
Tin	63	.....	.....	.....	.....	.....	37
Steel	60	.....	.....	.....	.....	.....	40
Porcelain enamel steel	4–5[a]	.....	60–70	.....	.....	.....	25–35
Mat-finished metal:							
Aluminum	.....	62	.....	.....	.....	.....	38
White oxidized aluminum	.....	70–75	.....	.....	.....	.....	25–30
Aluminum paint	.....	60–65	.....	.....	.....	.....	35–40
Mat surfaces:							
White plaster	.....	.....	90–95	.....	.....	.....	5–10
White blotting paper	.....	.....	80–85	.....	.....	.....	15–20
White paper (calendered)	4–5[a]	.....	75–80	.....	.....	.....	15–20
White paint (dull)	.....	.....	75–80	.....	.....	.....	20–25
White paint (semimat)	.....	2–4	70–75	.....	.....	.....	20–25
White paint (gloss)	4–5[a]	.....	70–75	.....	.....	.....	20–25
Black paint (gloss)	4–5[a]	.....	3– 5	.....	.....	.....	85–92
Black paint (dull)	.....	.....	3– 5	.....	.....	.....	95–97
Magnesium carbonate	.....	.....	98–99	.....	.....	.....	1–2
Plastic:							
Clear	.....	.....	.....	.....	60–80	.....	40–20
White diffuse	.....	.....	.....	.....	.....	5–35	65 95

[a] For angles up to 45 deg.; for angles greater than 45 deg., this value rises considerably; angle of incidence as X, Fig. 6.
[b] Smooth side toward light source.

13. Color of Objects.—Our impression of the color of objects is due to the color of the light that the object reflects or transmits to our eyes. In Sec. 2 it was stated that all objects absorb a certain portion of the light that falls upon them, but that all objects do not absorb the same proportion of light of the different wave lengths. It is through this different absorption that different objects have unlike colors. If all objects absorbed light in exactly the same manner, all objects would appear to have the same color. In order that things may appear in their true colors, they must be observed under white light, *i.e.*, light containing all three primary colors in the right proportion. An article which absorbs no light or which absorbs light of the three primary colors in the same proportion as they are combined to produce white light will transmit from its surface light in a condition unchanged from that in which the light fell upon the object. Such an object would appear white in color. An object which absorbs all or nearly all the light which falls upon it will have no color or, in other words, will be black. An object which absorbs all the green and violet rays will be red in color since it will transmit to our eyes only red light. In order that an object may appear in its true color the light falling upon it must contain light of the wave length that the object reflects or transmits. Thus, light falling upon a red object must contain red light if the object is to appear in its true color. A red object viewed under a light which contains only green and violet rays will appear black, since the object is capable of reflecting only red rays.

14. Light flux (which, as is explained later, is measured in lumens) is a flow of light, *i.e.*, light energy or light waves. Light flux always originates from some source of light, such as the sun, a candle, or an incandescent lamp. But light flux may be redirected by reflecting surfaces. The light flux which emanates directly or is reflected from objects to the human eye is the medium whereby the objects are seen. Although there is no actual flow of anything material in a flux of light, there is a flow of light waves.

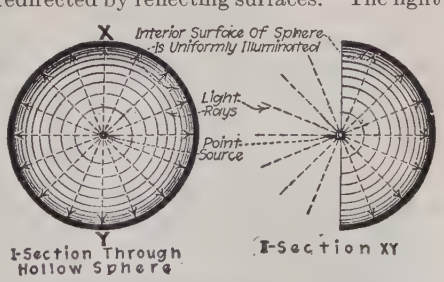


FIG. 9.—Diagrammatical illustration of light rays emitted by a point source of light.

15. A true point source of light (Fig. 9) is a luminous mathematical point which emits light flux uniformly in all directions. It is a theoretical concept which cannot actually exist. It is, however, used—and is necessary—for the development of the quantities and units used in lighting computations.

NOTE.—AN ACTUAL LIGHT SOURCE MAY BE CONSIDERED AS A POINT SOURCE, without prohibitive error, if the distance between the source and the location at which the source is viewed or examined is at least 10 times the greatest dimension of the source.

16. The luminous intensity of a given source of light in a certain specified direction is a measure of the ability of the source to project light in that direction. Luminous intensity is measured in a unit which is called either the candle or candle power.

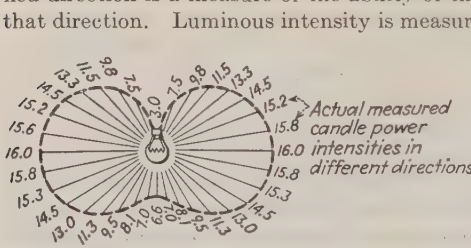


FIG. 10.—Luminous intensities in different directions around an incandescent lamp.

NOTE.—THE LUMINOUS INTENSITY OF ACTUAL LIGHT SOURCES IS GENERALLY GREATER IN CERTAIN DIRECTIONS THAN IN OTHERS. Thus, in Fig. 10, the luminous intensity of the lamp is greatest in the horizontal direction.

17. The candle or candle power is defined as the luminous intensity or light-producing power in the horizontal direction of a standard lamp which is made and used in accordance with U.S. Bureau of Standards specifications.

NOTE.—THE LUMINOUS INTENSITY OF AN ORDINARY SPERM CANDLE (Fig. 11) in the horizontal direction is about 1 candle. Thus was derived the name of the unit.

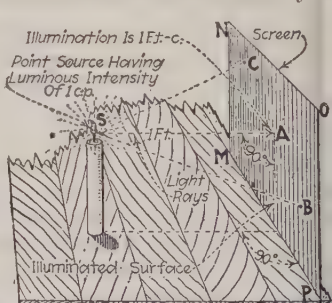


FIG. 11.—Illustrating an intensity of illumination of 1 ft.-c.

18. The true luminous intensity or candle power of a light source can be obtained only when the source is a true point source (Sec. **15**). But a true point source does not exist. It is merely a mathematical concept. Now, the luminous intensity of an actual light source, in a certain direction, is (Fig. 12) due to the combined effects of a number of point sources in the surface of the actual light source. Hence, the luminous intensity of an actual light source, in a given direction, as determined with a photometer (Sec. **26**), is not the true candle power (luminous intensity) but is the apparent luminous intensity (apparent candle power) in that direction.

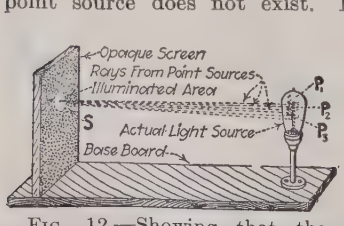


FIG. 12.—Showing that the illumination at point S is due to the combined effects of an infinite number of point sources, P_1, P_2, P_3, etc.

19. "Illumination" is measured in "foot-candles." The foot-candle is defined as that illumination which is produced (Fig. 11) by a 1-c.p. point source (or its equivalent) on a surface which is exactly 1 ft. distant from the point source.

EXPLANATION.—If, in Fig. 11, the light source S is assumed to be a point source of luminous flux, then the illumination at point A, which is exactly 1 ft. from S, is (by definition) 1 ft.-c. Since the illuminated surface $MNOP$ is a plane, the point A is the only point on the surface which has an illumination of 1 ft.-c. The illumination at any other point on the urface, such as B or C, is less than 1 ft.-c. because it is farther away from S than is P. If, however, the sphere of Fig. 9 has an internal radius of 1 ft. and the true point source (Sec. **15**) has a luminous intensity of 1 candle, then every point on the interior surface of the sphere will have an illumination of 1 ft.-c.

20. "Illumination" is really the density of the light flux which impinges on the surface of an illuminated object. The average density of anything on a surface may be numerically represented by the number of things on the whole surface divided by the number of unit areas in the surface. Thus, as will be further explained in Sec. **24,** if the light flux, in lumens, which impinges on a surface is divided by the area of that surface in square feet, the average illumination over the surface will be the result.

21. Light flux is measured in lumens. A lumen is defined as that quantity of incident light flux which will, when uniformly distributed over a surface having an area of 1 sq. ft., produce an illumination of 1 ft.-c. on every point of the surface.

NOTE.—WHEN LIGHT FLUX IMPINGES NONUNIFORMLY ON A SURFACE then a lumen is the quantity of light flux which will, on 1 sq. ft. area of the surface, produce an average illumination of 1 ft.-c.

22. A point source of light of 1 candle luminous intensity emits 12.57 lumens. It has been shown (Sec. **19** and Fig. 9) that a 1-c.p. point source of light located at the center of a hollow sphere of 1-ft. radius will produce an illumination of 1 ft.-c. on every point of the interior surface of the sphere. Now the superficial area of a sphere $= 4 \times 3.1416 \times r^2$. Hence, this 1-ft.-radius sphere will have an area of: $4 \times 3.1416 \times 1 \times 1 = 12.57$ sq. ft. Since every point on the surface of this sphere has an illumination of 1 ft.-c., there must, to satisfy the definition of the lumen (Sec. **21**), be as many lumens emitted by the 1-c.p. point source as there are square feet in the sphere's surface. The sphere has an area of 12.57 sq. ft. Therefore every 1-c.p. point source of light emits 12.57 lumens.

23. To obtain the output of a light source in lumens when its mean spherical candle power is known, substitute in the following formula. This formula is strictly accurate only for a true point source (Sec. **15**) of light, but it gives results sufficiently accurate for all practical purposes if the mean spherical candle power (Sec. **28**) is substituted for I. For the derivation of the formula, see the author's "Practical Elec-

tric Illumination."

$$F = 12.57 \times I \qquad \text{(lumens)} \quad (2)$$

where F = total light flux emitted by the light source, in lumens; and I = luminous intensity or candle power of a point source, in candles or with sufficient accuracy for most practical purposes, the mean spherical candle power of an actual light source.

Example.—The mean spherical candle power of a light source is 68.8. What quantity of light flux is emitted in lumens?

Solution.—By For. (2), light flux $F = 12.57 \times I = 12.57 \times 68.8 = 865$ lumens.

24. "Illumination" in "foot-candles" is really "lumens per square foot." From the definition of the lumen in Sec. **21**, 1 lumen of flux spread out over an area of 1 sq. ft. produces 1 ft.-c. average illumination over that surface; 2 lumens would produce 2 ft.-c., etc. Similarly, 10 lumens spread out over an area of 5 sq. ft. would produce an average illumination of $10 \div 5 = 2$ ft.-c. Likewise, 1 lumen spread out over an area of 2 sq. ft. would produce an illumination of $1 \div 2 = 0.5$ ft.-c. Thus, it is evident that lumens $\div$ sq. ft. area = average foot-candles illumination.

Example.—A room which has an area of 600 sq. ft. has 3,300 lumens of light flux impinging on the working plane. What is the average illumination, in foot-candles, on the working plane?

Solution.—By equation given above, average foot-candles illumination = lumens $\div$ sq. ft. area = $3{,}300 \div 600 = 5.5$ ft.-c.

25. The illumination, in foot-candles, which, from a light source, impinges on a surface, varies inversely as the square of the distance from the source. This is true absolutely for a true point source (Sec. **15**). It is approximately true if the distance is at least ten times the largest dimension of the light source.

Explanation.—Assume (Fig. 13) that the 1-c.p. point source P is placed at the center of a hollow spherical shell which has an internal radius D of 1 ft. Then, a section A of the shell, having an area of 1 sq. ft., will have on its inner surface an illumination of

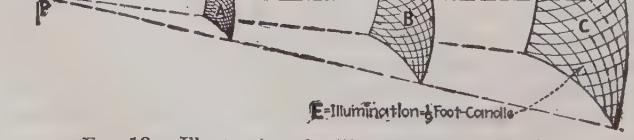


Fig. 13.—Illustrating the "inverse-square law."

1 ft.-c. This follows from the preceding discussions. Furthermore, from the definition of the lumen (Sec. **21**), just 1 lumen of flux is lighting this surface. Now, if the 1-ft.-radius sphere be removed and the 1-c.p. source be placed at the center of a 2-ft.-radius sphere, *i.e.*, one of double the radius, then the same light flux will be spread out over an area B of 4 sq. ft. (This follows because of the geometric fact that similar areas vary directly as the square of similar dimensions.) The illumination on B will be 1 lumen ÷ 4 sq. ft. = 0.25 ft.-c. Thus by doubling the distance from the source, the illumination has been quartered. Similarly, it can be shown for C that with the distance D increased three times the illumination provided by 1 lumen of flux is one-ninth of what it was with the distance of 1 ft. Thus, illumination varies inversely as the square of the distance from the source.

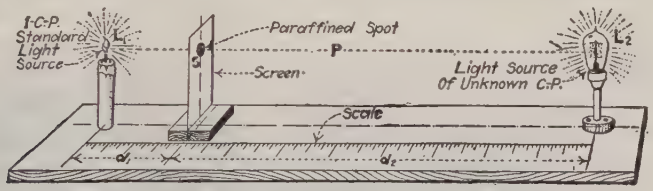


FIG. 14.—Illustrating the principle of the photometer.

26. The photometer (Fig. 14) is an instrument which is used for determining the luminous intensity, in candles, of a light source. Note that any determination made with a photometer gives apparent candle power. However (Sec. **25**), if the location at which the intensity is measured is at a sufficient distance (d_2, Fig. 14) from the source, then the source may for all practical purposes be considered as a point source, and the value obtained for the unknown candle power will be accurate well within the limits of error of experimental observation.

NOTE.—THE PRINCIPLE OF THE PHOTOMETER is illustrated in Fig. 14. A semitransparent spot S is made on the white unglazed-paper screen with a drop of melted paraffin. Suppose a light source L_1, which has been standardized, indirectly, with the Standard Light Unit at Washington, D.C., and found to have an intensity of 1 candle in the horizontal direction L_1S, is placed at a distance d_1 from the screen on a line P, which is perpendicular to the plane of the screen and which passes through the centers of S and L_2. The light L_2 is then moved backward and forward along P until the spot S is either invisible, or the least visible. When this adjustment has been made, both of the lights will be producing the same illumination on S. That is, the spot S intercepts the same amount of light flux from L_1 as from L_2. It has been shown (Sec. **25**) that the density of light flux, or the illumination, varies inversely as the square of the distance from the source of light. Hence if both faces of S are equally illuminated the apparent luminous intensity must vary as the squares of the distances. If $d_2 = 8$ ft. and $d_1 = 2$ ft., then the candle power of $L_2 = (64 \div 4) = 16$ times that of L_1. Or the luminous intensity of L_2 is 16 candles in the horizontal direction. It should be noted that the candle power of a light source will usually be different in different directions (see Fig. 10).

27. Mean horizontal candle power is the average of the candle powers of a lamp in all directions in a horizontal plane. This term is now applied only to special lamps for laboratory test work.

28. Mean spherical candle power is the average of the candle powers of a lamp in all directions. It is measured by putting the lamp in the

center of a sphere photometer (Fig. 15). The sphere has a small window of milk glass which is shielded from the direct rays of the lamp by a small opaque screen. The inner surface of the sphere is painted flat white for good reflection of the light. The candle power of the window is compared with the horizontal candle power of a standard lamp. This candle power must be multiplied by a constant for the particular sphere to take account of the loss of light absorbed on the inner surface of the sphere and in the glass window. The mean spherical candle power is used principally with the equation of Sec. **23** to obtain the lumen output in which the lamp is rated.

FIG. 15.—Sphere photometer. (*General Electric Co.*)

29. The efficiency of an electric-light source is stated in **lumens per watt.** This term is obtained by dividing the lumen output of the source by the watts input.

30. Candle-power Distribution Curves.—Since the common light-giving sources either alone or in conjunction with the reflecting equipment used with them do not have the same light-giving power or candle power in all directions, photometric graphs are employed in order to indicate the candle power of the source in all directions. Curves giving this information for a light source are called candle-power distribution curves or simply distribution curves. Fortunately, most lamps or lamps with their reflectors have the same candle power in all directions in any one horizontal plane. This fact enables the candle-power in any direction from the source to be determined from a single distribution curve which gives the candle powers in all directions in a vertical plane through the center of the light source.

31. How to Read a Photometric Graph.—In the photometric graph of Fig. 16, I. the candle power directly downward is indicated by measuring it off on the vertical to a given scale. Thus, XA represents the candle power directly below the light. Similarly the distances XB, XC, XD, XE, XF, and XG represent to scale candle powers around the light at angles above the vertical of 15, 30, 45, 60, 75, and 90 deg. Similarly the candle powers above 90 deg. can be measured off to the given scale along lines at their respective angles. These points are then joined by a continuous line $GFED$, etc., and this line, completed for the 360 deg., is called the photometric distribution graph of the light source. Figure

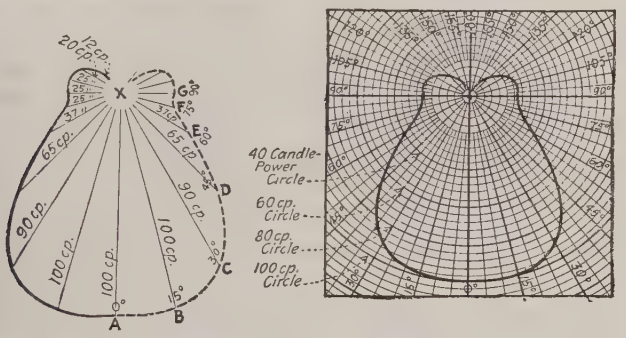


Fig. 16.—Photometric graphs.

16, I shows such a completed photometric curve, but in practice it is customary to use circular lines, as indicated on Fig. 16, II, to show the scale to which the candle powers are plotted. The candle power of the light unit can be measured at as few or as many angles as necessary, the accuracy of the resultant graph being largely determined by the number of angles taken.

32. The area of the distribution graph is not proportional to the amount of light given off. B (Fig. 66) represents a smaller total flux, by an amount equal to the absorption in the reflector, than does graph A, though it has a larger area. Such a graph as B is useful for determining the intensity of light at any given angle and for determining the total luminous output, as explained in Sec. **33.** These data may be required for any one of a number of practical operations.

33. The method of computing from its distribution graph the total flux, in lumens, emitted by a light source is this: From the distribution graph of any light unit, as Fig. 16, take the candle power at 5 deg. and multiply it by the 0–10 factor as given in Table 35. This gives the lumens in the 0–10-deg. zone. Similarly, to obtain the lumens in the 10–20-deg. zone, take the candle power at 15 deg. and multiply it by the 10–20-deg. factor as given in Table 35. The total lumens emitted in any

large zone are obtained by adding the lumens of all the 10-deg. zone contained in the large zone. If the sum total of the lumens is thus obtained for the 0–180-deg. zone, the result is the total flux, in lumens, emitted by the source.

Example.—What is the total flux emitted by a light source having a distribution graph as shown in Fig. 16?

Solution:

Deg. (1)	Candle power (2)	Zone factor (3)	Lumens (4)
5	100	0.095	9.50
15	98	0.283	27.45
25	94	0.463	43.50
35	84	0.628	52.75
45	66	0.774	51.10
55	46	0.897	41.25
65	33	0.992	32.71
75	27	1.058	28.55
85	26	1.091	28.37
95	26	1.091	28.37
105	25	1.058	26.48
115	24	0.992	23.80
125	20	0.897	17.94
135	15	0.774	11.60
145	12	0.628	7.54
155	8	0.463	3.70
165	4	0.283	1.13
175	4	0.095	0.38
			Total = 436.12

Total flux emitted = 436.12 lumens.

Column 2 is obtained from the graph (Fig. 16). Column 3 is obtained from Table 3. Column 4 is obtained by multiplying the values in Column 2 by the corresponding values of Column 3.

NOTE.—THE TOTAL FLUX IN LUMENS EMITTED BY A LIGHT SOURCE MAY BE COMPUTED GRAPHICALLY as follows: On the candle-power distribution graph (Fig. 16) measure the horizontal distance between the vertical axis (0–180-deg. line) and the point where the candle-power graph crosses the 5-deg. line. Then lay off this distance on the candle-power scale to which the distribution graph is plotted. Multiply the value thus obtained by 1.1, and the result is the quantity of light flux, in lumens, emitted by the light source in the 0–10-deg. zone. To determine the flux in any 10-deg. zone, it is only necessary to measure the horizontal distance between the vertical axis and the point where the candle-power graph crosses the center of the 10-deg. zone under consideration and then proceed as above. To obtain the total lumens emitted in any large zone lay off the horizontal distances between the vertical axis and the point where the candle-power graph cuts the center of each 10-deg. zone contained within the large zone successively along the edge of a strip of paper. Then lay off the total length on the candle-power scale and multiply the result by 1.1.

34. The mean spherical candle power (Sec. **28**) of a light source may be determined (1) directly, by means of the sphere photometer (Sec. **28** and Fig. 15), and (2) indirectly, by computing the total lumens from the distribution graph, as explained in the preceding paragraph, and dividing the result by 12.57.

Example.—What is the mean spherical candle power of the light source, the distribution graph of which is shown in Fig. 16.

Solution.—By example under Sec. **33**, the total flux of the source = 436.12 lumens. The mean spherical candle power = 436.12 ÷ 12.57 = 34.6.

35. Factors to Obtain the Lumens in the 10-deg. Zones around a Light Source.—To obtain the lumens in any zone, multiply the candle power at the center of the zone by the factor for that zone.

Degree zones		Factor	Degree zones		Factor
0–10	170–180	0.095	50–60	120–130	0.897
10–20	160–170	0.283	60–70	110–120	0.992
20–30	150–160	0.463	70–80	100–110	1.058
30–40	140–150	0.628	80–90	90–100	1.091
40–50	130–140	0.774			

36. The foot-candle meter (sometimes called **sight meter**) is an instrument for measuring illumination directly in foot-candles. It consists of one or two photronic cells connected to a microammeter. When light falls on the photronic cell a voltage is generated and current flows through the meter approximately in proportion to the foot-candle illumination on the cell. The small pocket type of meter is usually called a sight meter (Fig. 17). It has a single photronic cell and a single scale, calibrated in foot-candles. The scale is also calibrated in visual tasks to be done so that the meter may be used readily by persons not familiar with technical terms. The meter is placed with the window of the photronic cell parallel to the plane on which it is desired to measure the illumination. Higher values of illumination (such as those of daylight intensity) may be measured by slipping a screen called a multiplier over the front of the cell. Thus, part of the light is absorbed

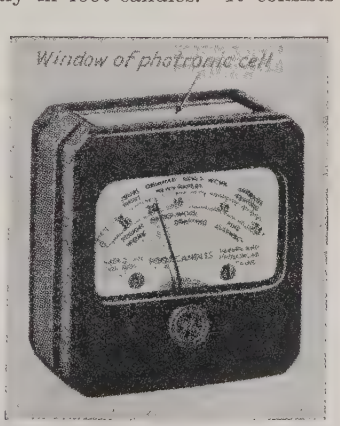


FIG. 17.—The sight meter. (*General Electric Co.*)

by the screen, and the illumination will be the value read on the mete multiplied by the constant for the multiplier.

Larger and more accurate meters (Fig. 18) have two cells connecte in parallel to increase the current output. They also have two or thre different resistors which can be connected in series with the meter circu

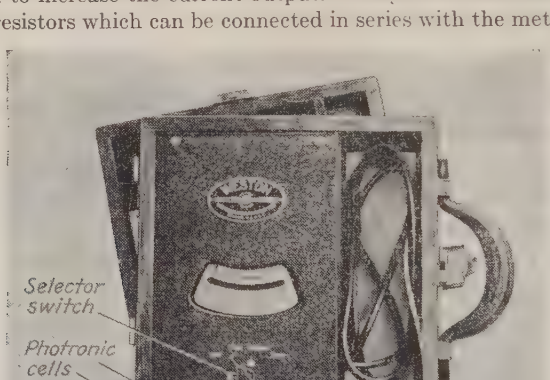


FIG. 18.—The foot-candle meter. (*Weston Co.*)

by use of a toggle selector switch. The dial is provided with sever different scales to correspond to the different resistors. The light outpu of the photronic cells decreases with age and use, so that they should b calibrated frequently for accurate results. Calibration may be checke by setting up in a dark room (Fig. 19) a laboratory standard lamp whos

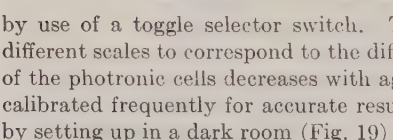


FIG. 19.—Diagram for calibration of foot-candle meter.

mean horizontal candle power known (Sec. **27**). The voltag applied to the lamp must be th exact value for which it is cal brated. The cell should be hel in a vertical position about 2 3 ft. horizontally from the lamp Then, by definition,

$$\text{Foot-candles} = \frac{\text{c.p.}}{S^2} \quad (3$$

where c.p. = candle power lamp; and S = distance from lamp to cell in feet.

Foot-candle meters are usually calibrated with incandescent Mazd lamps and therefore are strictly accurate only when used with light fro incandescent lamps. They may be obtained calibrated for use with da light fluorescent lamps, however. When used with any other quality

color of light the results are good only for very rough comparisons, the accuracy decreasing as the color of the light is further removed from the color of the light for which the meter was calibrated.

37. Glare (Fig. 20) is defined as any brightness within the field of vision of such character that it will cause interference with vision or eye fatigue.

NOTE.—GLARE MAY BE SUBDIVIDED INTO THREE DIFFERENT CLASSES: (1) Direct glare (Fig. 20, II), which results when one looks directly at a brilliant light source. (2) Contrast glare, which is caused by brightness contrast. An example of this is the visual discomfort produced by a brilliant automobile headlight shining in the eyes on a dark night. The same headlight would cause no discomfort in the daytime. The annoyance experienced at night is due solely to the contrast between the bright headlight and the dark surroundings. (3) Reflected glare (Fig. 20, I) which is produced by light being reflected directly into the eyes from a polished, a white, or a light-colored surface. Glass desk plates, highly polished furniture, glazed paper, and mirrors may occasion reflected glare.

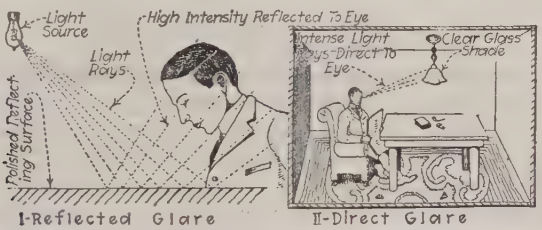


FIG. 20.—Illustrating methods of causing glare.

38. "Brightness" is the property of lighted objects which enables them to be seen by virtue of the light issuing from them. Technically, brightness is the density of the light flux issuing or projected from a light source or from some illuminated surface.

NOTE.—THE RELATION BETWEEN BRIGHTNESS AND ILLUMINATION. Illumination is the density of the light flux impinging on an illuminated surface. Just as illumination measures incident-light-flux density, so brightness measures issuing-light-flux density. It is due solely to the light issuing or reflected from things that we see. There might be great illumination (incident-light-flux density) on a dead-black object in a room with dead-black walls, and yet that object would be invisible, because the black would absorb (see Table 9) all the light which impinged on it and would reflect none to the eye.

39. The units of brightness are the **lambert,** the **millilambert,** the **foot-lambert,** and the **candle per square inch.** The lambert is by definition the brightness of a perfectly diffusing surface which radiates or reflects 1 lumen per sq. cm., while the millilambert is 0.001 of this value. The foot-lambert is the brightness of a surface which radiates or reflects 1 lumen per sq. ft. As its name implies the candle per square inch is the brightness of a surface which radiates 1 candle power per sq. in. The lambert and the candle per square inch are commonly used for high brightness such as light sources, while the millilambert and the foot-lambert are used for designating ordinary illuminated surfaces.

40. The working equations for brightness computations are:

$$b = 2.05\,L \qquad (3)$$

$$F = 6.45\,SL \qquad (4)$$

where b = brightness in candles per square inch; L = brightness in lamberts; F = total light flux in lumens; and S = area of the surface in square inches.

Example.—A light source has a brightness of 500 c.p. per sq. in. What is its brightness expressed in lamberts?

Solution.—By For. (4),

$$L = \frac{b}{2.05} = \frac{500}{2.05} = 243.5 \text{ lamberts}$$

Example.—An incandescent-lamp filament has a surface area of 0.4 sq. in. and emits 1,580 lumens. What is its brightness in lamberts?

Solution.—By For. (5),

$$L = \frac{F}{6.458} = \frac{1{,}580}{6.45 \times 0.4} = 612 \text{ lamberts}$$

41. The relation between the illumination incident on and the brightness reflected from an illuminated surface may be understood from consideration of the following facts: No surface, however smooth, is a perfect reflector, since some of the light flux impinging on the surface will be absorbed thereby. Therefore, in computing the surface brightness resulting from the reflection of the impinging light rays or illumination the coefficient of reflection (Table 9) of the material must be considered. The brightness equals the illumination times the coefficient of reflection.

$$\text{Milli-}L = 1.076 \times E \times m \qquad \text{(millilamberts)} \qquad (5)$$

where Milli-L = average surface brightness over the surface under consideration in millilamberts; E = the incident illumination on the surface in foot-candles; and m = the absolute coefficient of reflection (Table 9) of the surface material.

Example.—A surface of ordinary foolscap paper has an illumination of 5 ft-c. What is its brightness?

Solution.—The coefficient of reflection of ordinary foolscap is (Table 9) 0.70. By For. (5),

$$\text{Brightness} = 1.076 \times E \times m = 1.076 \times 5 \times 0.70 = 3.77 \text{ millilamberts}$$

42. Conversion Factors for Various Units of Brightness

Values in units in this column × conversion factor = values in units at top of column	Candles per sq. in.	Lamberts	Millilamberts	Foot-lamber
Candles per sq. in.	1	0.487	487	452
Lamberts	2.054	1	1,000	929
Millilambert	0.00205	0.001	1	0.92
Foot-lambert	0.00221	0.00108	1.076	1

43. The maximum brightness beyond which glare will result (see Sec. **37** for Glare) is specified by Ward Harrison in his "Electric Lighting." Ordinarily, the brightness of a lighting unit which is in the central portion of the visual field should not exceed from 1 to 1.5 lamberts (2 to 3 candles per sq. in. of projected area). Higher values of brightness will produce a sensation of glare. If the eyes are not to be fatigued when the unit is viewed continually, the brightness should not exceed 0.25 lambert. It should be noted that the maximum permissible brightness is somewhat influenced by the darkness of the surroundings (see Contrast Glare under Sec. **37**).

44. Brightness of Light Sources

Source	Approximate Lamberts
Incandescent lamp with opal globe	0.24 – 1.46
Incandescent lamp inside frosted globe	7 – 15
Fluorescent lamp, white and daylight	1.2 – 2.6
Fluorescent lamp, green	2.4 – 3.6
Fluorescent lamp, red	0.12 – 0.23
Fluorescent lamp, pink, blue, gold	0.83 – 1.8
Candle flame	1.46 – 1.95
Cooper-Hewitt lamp	4.9 – 9.8
Acetylene-burner flame	29 – 50
Vacuum-incandescent-lamp filament	460 – 700
Gas-filled-incandescent-lamp filament	3,000 –4,000
Neon tube (red)	0.24
Neon-mercury tube (green or blue)	0.05 – 0.1
Mercury arc (quartz tube)	290 – 490
Sky	0.7 – 2.0
Sun, on horizon	1,000
Sun, 30 deg. above horizon	243,000
Sun, at noon	450,000
Ceiling over indirect-lighting fixture	0.01 – 0.1
Walls when lighted by diffused daylight	0.001– 0.05

ELECTRIC-LIGHT SOURCES

45. Electric-light sources may be classified as follows:

A. Visible-light sources.
  1. Incandescent.
  2. Fluorescent.
  3. Gaseous discharge.
     a. Cooper-Hewitt mercury vapor (low pressure).
     b. Mercury Mazda (high pressure, high intensity).
     c. Sodium vapor.
     d. Neon.

B. Ultraviolet-light sources.
  1. Sunlight lamps.
  2. Ultraviolet projection lamps.
  3. Germicidal lamps.

C. Infrared heating lamp.

INCANDESCENT LAMPS

46. The incandescent lamp consists of a filament which is a highly refractory conductor mounted in a transparent or translucent glass bulb and provided with a suitable electrically connecting base. The filament is heated by the passage of an electric current through it to such a high temperature that it becomes incandescent and emits light. In incandescent lamps of the older types the air was, insofar as practicable, exhausted from the space within the bulb and surrounding the conductor (filament), forming a partial vacuum. But in many of the modern lamps this space is filled with an inert transparent gas—like nitrogen , for example. The conductor must have a high melting point or high vaporizing temperature and a high resistance; it must be hard and not become plastic when heated. In vacuum-type lamps the vacuum must be good, not only to prevent the oxidation of the filament, but also to prevent the loss of heat, which would reduce the efficiency. In non-vacuum-type lamps (gas-filled lamps) the gas used must be inert so as not to combine chemically with the filament material. The bulb must be transparent or translucent to permit the passage of light, not porous, so that it will retain the vacuum or inert gas, and strong to withstand handling and use.

47. Classification of incandescent lamps according to method of manufacture.

1. Mazda.
   a. Type B, vacuum.
   b. Type C, gas filled.
2. Non-Mazda.
   a. Manufactured by other companies under Mazda patents.
   b. Manufactured by independent companies.

48. Mazda lamps are lamps manufactured by the principal lamp manufacturing companies in the United States under rigid inspection service maintained by the Electrical Testing Laboratories. This organization, which operates the Mazda service independently of the manufacturing companies themselves, maintains inspectors in each Mazda-lamp factory. After the lamps have passed the factory's rigid quality tests they are subject to sampling, inspection, and test by the Electrical Testing Laboratories' inspector. Mazda lamps are subject to over 480 tests and inspections to ensure uniform quality.

49. Mazda B or vacuum lamps are those lamps of which practically all air and gases have been removed from the bulbs, so that the filament operates in a vacuum. Practically all small lamps up to the 25-watt size are Mazda B lamps.

50. Mazda C or gas-filled lamps are those which are filled with a mixture of argon and nitrogen gas. The presence of this inert gas retards the evaporation of the filament and allows the filament to be operated at

higher temperature, which gives considerably higher light output with the same useful life. The convection currents in the hot gas carry the evaporated tungsten particles to the upper portion of the bulb where they are deposited on the relatively cooler part of the glass. The blackening of the bulb thus occurs in a location which causes very little of the useful light to be absorbed. Lamps of the 40-watt size and larger are Mazda C lamps.

51. Non-Mazda lamps are those which are made to sell at a lower price than the Mazda lamps. The type which is manufactured by companies licensed to use the Mazda patents and Mazda machinery and manufacturing methods is produced under the same conditions as are Mazda lamps except that they are not controlled by Mazda inspection men. Such lamps may be of a quality equally as satisfactory as Mazda lamps and usually sell for a 5 to 7 per cent greater discount on account of the saving in cost of the Mazda inspection service. Large purchasers of these lamps may use the Electrical Testing Laboratories' service to check the quality from time to time.

52. Lamps manufactured by companies not using the Mazda patents and methods are cheaper to manufacture on account of fewer inspections and tests with correspondingly less spoilage and rejections. Also, in many cases, especially in foreign countries, the wages paid to labor are lower. For these reasons the quality of the lamps is much less uniform, the lumen-per-watt efficiency may be lower, and the life is much less certain. For locations where the number of hours' use per year is low the lower initial cost of these lamps is attractive. For the majority of locations, however, the greater cost of the electricity consumed during the life of the lamp and the more frequent replacement of lamps make the overall cost much greater than for Mazda lamps. With usual electric rates the cost of electricity consumed during 1,000 hours' use is much greater than the cost of the lamp itself. Therefore, any apparent saving in the cost of the lamp may be lost in electricity wasted by it. From the example in Sec. **84,** note that the electricity costs about ten times as much as the lamp itself.

Anyone purchasing non-Mazda lamps is advised to obtain them from a reliable manufacturer so as to be sure of obtaining as high a quality lamp as possible. He should also have the lumen output and life of sample lamps checked occasionally by the Electrical Testing Laboratories. Then from the prices paid for the lamps and from the cost of the electrical energy he can determine whether he is saving money over the cost of using Mazda lamps.

53. Classification of Mazda Incandescent Lamps.—The standard Mazda incandescent lamps may be classified in four different ways, according to:

1. The shape of the bulb.
2. The finish of the bulb.
3. The type of base.
4. The type of service.

54. Classification According to Shape of Bulb (Fig. 21).—The standard-line shape is employed for general-lighting-service lamps up to and including the 100-watt size. Lamps of 150 watts and larger for general lighting service are made in the pear shape. The other shapes are utilized

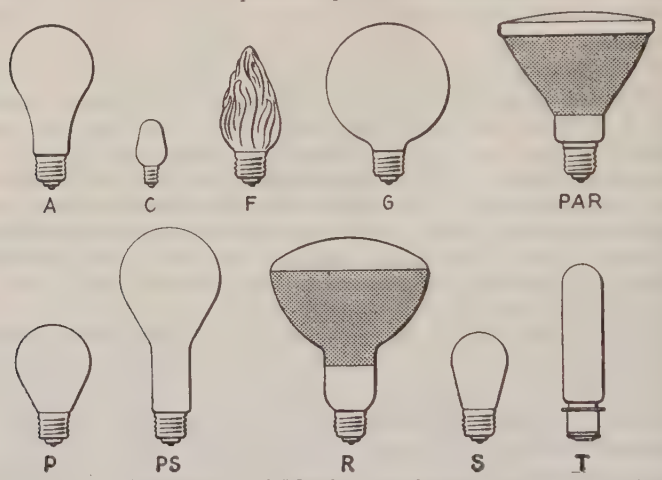


FIG. 21.—Bulb designations of Mazda incandescent lamps. (*Westinghouse Electric & Manufacturing Co., Lamp Division.*)

for lamps designed for special classes of service. Lumiline lamps are included in the tubular classification.

Shape of bulb	Designating letter	Shape of bulb	Designating letter
Standard line	A	Pear shaped	P or PS
Candelabra	C	Reflector	R
Flame shaped	F	Straight side	S
Globular	G	Tubular	T
Parabolic	PAR		

Lamps are designated by the letter and figure as PS-30. The letter indicates the shape of bulb and the figure the diameter of the bulb in eighths of an inch. Thus, a PS-30 lamp is a lamp with a pear-shaped bulb with a diameter of $3\frac{0}{8}$, or $3\frac{3}{4}$ in.

55. Classification According to Finish of Bulb.

1. Clear.
2. Inside frosted.
3. White bowl.
4. Silvered bowl.
5. Daylight.
6. Inside colored.
7. Outside colored.
8. Colored glass.

56. Finish of Bulbs.—Incandescent lamps may be obtained with the ulbs finished in several different ways as listed in Sec. **55.** With the lear lamps the bulb is made of clear glass which leaves the filament xposed to view. Clear-bulb lamps are used with reflecting equipment hich completely conceals the lamp from view. They are employed in ome cases with open-bottom types of reflecting equipment, when the nits are mounted so high that the lamps are not in the line of vision. nside-frosted lamps have the entire inside surface f the bulb coated with a frosting which leaves he exterior surface perfectly smooth. This nish conceals the bright filament and diffuses the ght emitted from the lamp. Inside-frosted mps are used with open-bottom types of reflect-ng equipment and in places where no reflecting quipment is employed. White-bowl lamps have he lower portion of the bulb sprayed with a white ashable enamel (Fig. 22). This increases the ze of the visible light source when viewed from elow, reducing the apparent brilliancy and iffusing the light rays so as to reduce the danger glare. The white-bowl finish is the one nployed generally for lamps of larger size than 00 watts, when used with open-bottom types of flectors. Silvered-bowl lamps have a coating mirror silver on the lower half of the bowl, hich shields the brilliant filament and forms a ghly efficient reflecting surface for indirect ghting. The upper part of the bulb is inside frosted to eliminate streaks nd shadows of fixture supports. Silvered-bowl lamps should be used nly in fixtures designed for them, because the silvering directs the heat ward the socket assembly, which will therefore tend to operate at a gher temperature than with clear lamps.

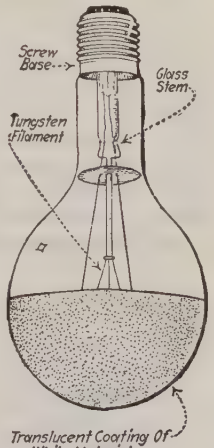


FIG. 22.—White-bowl Mazda C lamp.

57. Daylight lamps have a blue bulb made of a special blue-green glass. oon sunlight, which is usually considered as the standard white light, nsists of a combination of equal amounts of the three primary colors: d, green, and violet. The ordinary Mazda lamp produces light in which e red rays predominate. The blue-green glass of the bulb of daylight mps absorbs part of the reddish rays emitted by the filament of the mp, giving a resultant light which approaches the whitness of noon nlight. The glass absorbs about one-third of the total light emitted by e filament. Consequently, in order to obtain a given intensity of umination of the daylight quality, it is necessary to use 50 per cent ore wattage than would be required with clear lamps. These lamps are dely used for show-window and other lighting for which sunlight color

is desirable. They are, however, being displaced by the more efficie and more economical daylight fluorescent lamp.

58. Colored Bulbs (Westinghouse Lamp Co.).—Colored light may produced by means of clear or inside-frosted Mazda lamps in combinat with color accessories such as glass caps, globes or hoods, glass plates, gelatin screens, or by means of lamps with colored bulbs.

Colored bulbs are of two varieties, outside coated and inside coate

Outside-coated bulbs are those which have been coated by dipp them into some coloring material such as lacquer. These lacquers p vide a transparent coating with little diffusion and are not permane After relatively short periods the coating chips and peels and hence used only in cases where permanency is not a factor.

Inside-coated bulbs, as the name would imply, are coated on the ins of the bulb. This process provides a coating of pleasing appearan which will neither chip, peel, nor fade, and as inside-coated lamps relatively inexpensive they are widely used.

59. Classification According to Type of Base (Fig. 23).

1. Bayonet.
2. Candelabra.
3. Intermediate.
4. Medium.
5. Three-contact medium.
6. Admedium.
7. Mogul.
8. Three-contact mogul.
9. Disk.
10. Medium prefocus.
11. Mogul prefocus.
12. Medium bipin.
13. Medium bipost.
14. Mogul bipost.

60. Lamp Bases.—There are in use a number of different types bases for incandescent lamps (Fig. 23). Of these, the bayonet, c

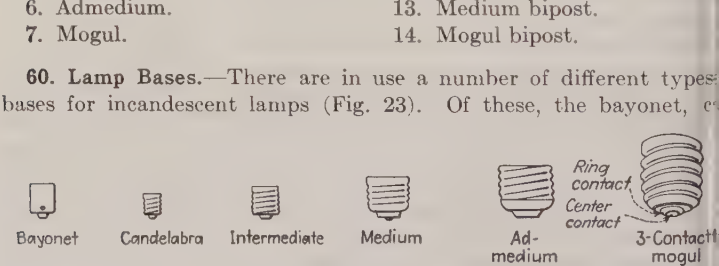


FIG. 23.—Bases for Mazda incandescent lamps. (*Westinghouse Electri Manufacturing Co., Lamp Division.*)

delabra, and intermediate base are used on the small-sized (miniatu lamps. The medium base, used on general-service lamps of 300 w and less, is the most common type. The mogul base is used on s

of 300 watts and up. The admedium is slightly larger in diameter than the medium and is used on some of the mercury Mazda lamps. The three-contact base is used with a three-lite type of lamp. The disk base is used on lumiline lamps.

The medium and mogul prefocused bases are used on certain types of concentrated-filament lamps, such as those for picture projection and aviation service, where it is desirable to have the light source accurately located. The medium bipin base is for fluorescent lamps. The medium bipost base is made in 500-, 750-, and 1,000-watt lamp sizes for use principally with indirect fixtures, where it allows a better design of fixture and better radiation of heat than is obtainable with the mogul-base type. For the very large size lamps of 1,500 watts and up for floodlighting service the mogul bipost is the standard.

61. Classification of Mazda Incandescent Lamps According to Type of Service:

1. General lighting service.
   - *a.* Clear bulb.
   - *b.* Inside-frosted bulb.
   - *c.* White-bowl bulb.
   - *d.* Silvered-bowl bulb.
2. Special lighting service.
   - *a.* Lumiline lamp.
   - *b.* Tubular lamp.
   - *c.* Daylight lamp.
   - *d.* Inside-colored bulb.
   - *e.* Natural-colored bulb.
   - *f.* Outside-colored bulb.
   - *g.* Flame-type bulb.
   - *h.* Rough-service lamp.
3. Miscellaneous lighting service.
   - *a.* Traffic-signal service.
   - *b.* Three-lite lamp.
   - *c.* Showcase reflector lamp.
   - *d.* High-voltage service.
   - *e.* Country-home service.
   - *f.* Projection and stereopticon service.
   - *g.* Spotlight and floodlight service.
   - *h.* Street series service.
   - *i.* Street-railway service.
   - *j.* Aviation service.
   - *k.* Train and locomotive service.
   - *l.* Projector and reflector lamps.
   - *m.* Photo service.

62. General-lighting-service lamps are those of 115-, 120-, or 125-volt rating for the ordinary uses in homes, stores, offices, schools, factories, etc.

63. Special-lighting-service lamps are for use in similar locations, but they have some special design feature, such as shape or color of bulb. The lumiline lamp has a long bulb 1 in. in diameter and is used for decorative lighting and for concealed lighting where a narrow bulb is required. It is being displaced by the fluorescent lamp, although the lumiline fixtures are still much cheaper than the fluorescent fixtures. The tubular lamp is shorter in length than the lumiline.

64. Colored and tinted lamps are available in a number of different types (see Sec. **58**). For interior use in ornamental fixtures in homes, clubs, lobbies, and foyers the outside-coated type is generally satisfactory, although the frosting may be scratched or the color removed by cleaning.

For exterior use on exposed signs, festoons, Christmas trees, etc., t inside-colored type should always be used. The Verd-A-Ray Corp. Toledo, Ohio, makes a yellow inside-colored lamp called an "inse repellent lamp." The quality of the color such that insects do not fly around it as mu as they do with clear or inside-frosted lam It is thus recommended for use outdoors in t summer on porches, on roadside stands, gardens, etc.

FIG. 24.—Traffic signal lamp. (*Westinghouse Electric & Manufacturing Co.*)

65. Vibration and rough-service lamps made in 50- and 100-watt sizes for 115, 120, 125 volts. They are designed for use un severe vibration, or shock conditions such for mounting on high-speed machinery, or extension cords in garages. Since they are m expensive and less efficient than the gene lighting-service type, their use should be stricted to locations where the general-serv type has proved unsatisfactory.

66. The traffic-signal lamp (Fig. 24) is a watt clear lamp, designed with a short li center length, for focusing the rays to give a signal indication of requi brightness. The lamp is designed for a 2,000-hr. life to minimize placements. It is available in 115-, 120-, or 125-volt ratings.

67. The three-lite lamp has two separate filaments in the one bulb (Fig. 25). One filament consumes double the wattage of the other, and the filaments may be lighted separately or together to produce three different levels of illumination, namely, 50/100/150 watts, or 100/200/300 watts. These lamps are particularly applicable to study lamps, reading lamps, and indirect floor lamps so that the user, with a single lamp, can adjust the illumination from that for decorative and casual use to full brilliancy for close seeing. They may also be used in stores so that daylight may be supplemented with an economical use of elec light so that the illumination may be varied to suit different occasi

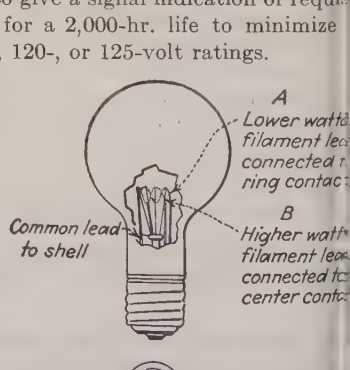


FIG. 25.—Three-lite lamp. (*Gen Electric Co.*)

68. The showcase reflector lamp (Fig. 26) is made with a tubular b with the upper half inside-aluminized so that it may be used in showca shelves, speakers' stands, etc., in an ordinary socket without any reflec

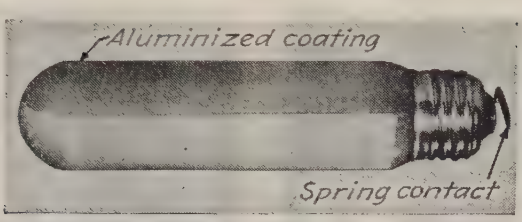


FIG. 26.—Showcase reflector lamp. (*General Electric Co.*)

A spring contact on the base allows for adjustment of the lamp in the socket in order to throw the light rays in any desired direction.

69. High-voltage-service lamps, rated at 230 and 250 volts are available for use in locations where only the higher voltage is available. These lamps are less rugged and less efficient than the general-lighting-service type. The reason for this is that the filament has to be of longer and finer wire to have sufficient resistance to limit the current to approximately one-half the value for the same-wattage, general-service lamp. For this reason their use in any new installation where the lower voltage could be made available is not encouraged.

70. Country-home-service lamps are rated for 30 volts and designed for operation on battery-generator sets as used on farms and in other places where central-station service is not available.

71. Picture-projection lamps (Fig. 27) are for use in motion-picture and stereopticon projectors for throwing the picture on the screen. This lamp has a tubular bulb with a concentrated filament, which permits a high-wattage lamp to be encased in a small bulb. Owing to the high operating temperature of the filament the rated life is only from 25 to 50 hr.

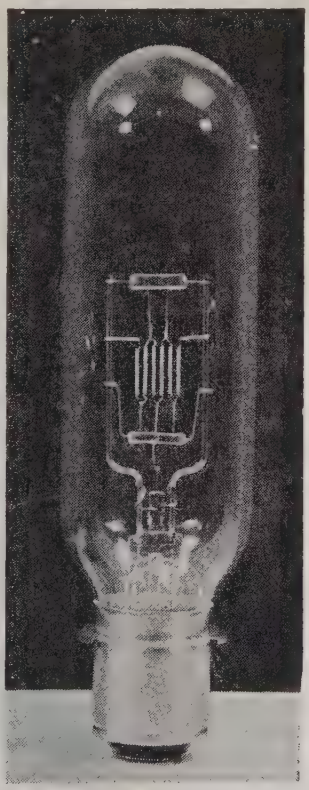
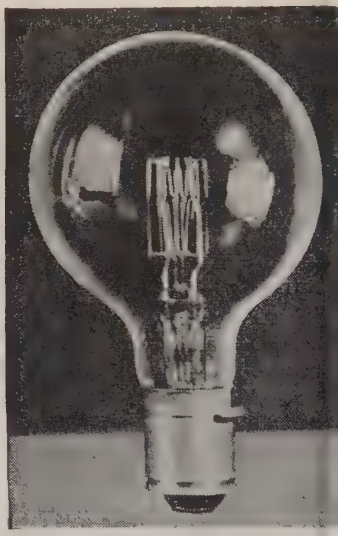


FIG. 27.—Picture-projection lamp. (*Westinghouse Electric & Manufacturing Co.*)

72. Floodlighting lamps (Fig. 28, I) are made with a globular bulb and a closely concentrated filament. This design facilitates locating the filament at the focal center of parabolic reflectors to give a narrow beam of light which can be projected relatively long distances. Its use is for floodlighting of building exteriors.

I. Floodlighting lamp



II. Spotlight

FIG. 28.—Floodlighting and spotlighting lamps. (*Westinghouse Electric Manufacturing Co.*)

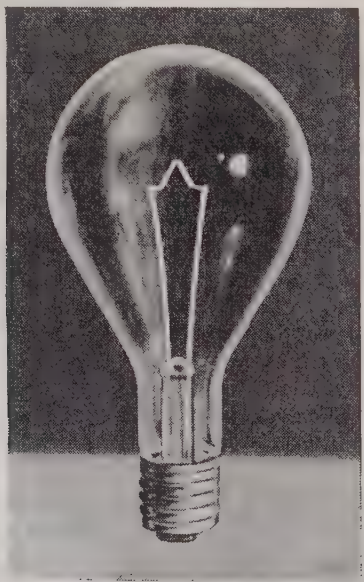
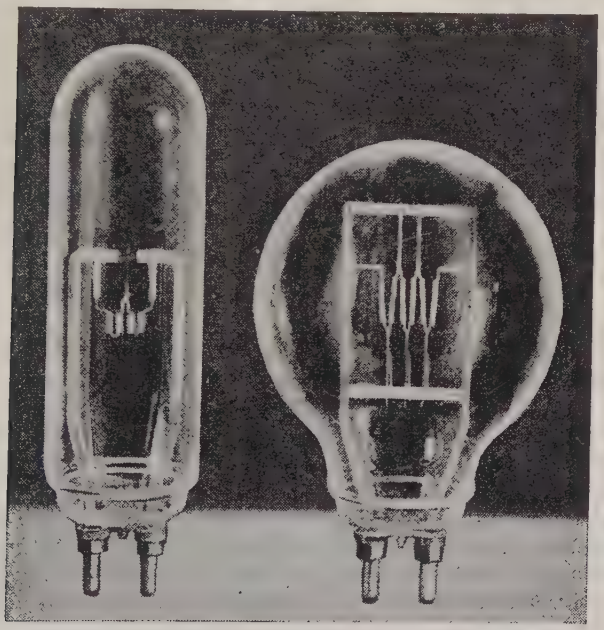


FIG. 29.—Street-lighting-service lamp. (*Westinghouse Electric & Manufacturing Co.*)

Spotlight-service lamps (Fig. 28, II) are similar to the floodlighting-ervice lamps except that they are made with a prefocus base for more ccurate control and concentration of the light beam. Their principal se is in theaters for spotlighting of actors on the stage.

73. Street-lighting-service lamps (Fig. 29) are similar to the general-ghting-service clear lamps except that they are designed for constant-urrent operation at 6.6, 15, or 20 amp. These lamps have a rated aboratory life of 2,000 hr. at absolutely constant current. Their life



. 30.—Aviation-service lamps. (*Westinghouse Electric & Manufacturing Co.*)

der actual operating conditions of somewhat varying current is more to be 1,500 hr. or less.

74. Street-railway-service lamps operate five-in-series on the trolley tage of 550 or 600 volts, for general illumination, destination signs, ., in streetcars. There are also 30-volt and 60-volt types which oper- with automatic short-circuiting relays to short the lamp out of the cir- t when the lamp burns out. These types operate with approximately -in-series or 10-in-series on 600 volts.

75. Aviation-service lamps (Fig. 30) are used for airway beacons, for dlighting of landing fields, and for landing lamps on aircraft. They made in tubular and globular bulbs, with bipost or prefocus base, and 12, 32, 115, 120, or 125 volts. Airport boundary lights take a

6.6-amp. street-lighting-service lamp described in Sec. **73.** Gener lighting-service lamps in the 50- and 100-watt sizes are used in obstru tion lights.

76. Train-lighting-service lamps are for use on railroad trains from battery, axle-generator system. They are rated for 30, 32, 60, or 64 vol

77. Reflector and projector lamps (Fig. 31) are made with a parabol shaped bulb having a mirrored surface on the inside of the neck, and fixed-focus filament. They can be used with a plain socket to form

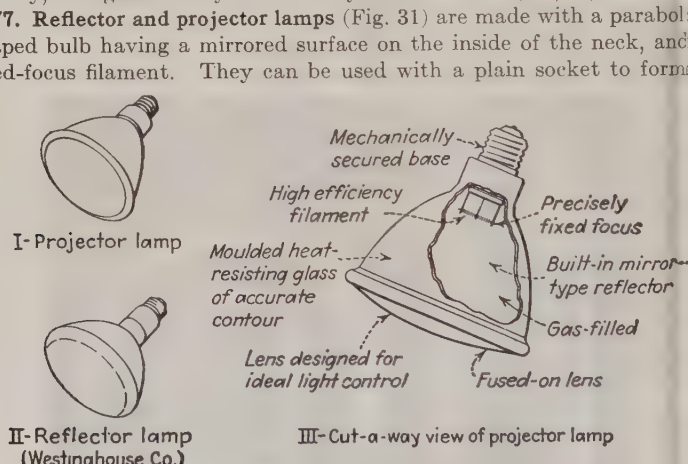


FIG. 31.—Reflector and projector lamps.

highly efficient spotlight. The projector type has a lens built into face of the lamp for better control of the light. This lamp is made heat-resisting glass so that it may be used either indoors or where expo to the weather. The reflector type has an inside-frosted glass bulb wh is not weatherproof and does not provide so accurate control of the li but costs only about two-thirds as much as the projector type. B types may be obtained in either a concentrating-spotlight or a wide-flo light type.

78. Photo-service lamps are made in two types:

1. Photoflash lamps.
2. Photoflood lamps.

The photoflash lamp (Fig. 32) consists of a bulb containing magnesi foil in an atmosphere of oxygen. When the lamp is connected t source of voltage, which may be either two flashlight cells or a 110- 125-volt power circuit, the foil burns with a brilliant flash lasting ab $\frac{1}{50}$ sec.

The photoflood lamp is similar to the regular inside-frosted inc descent lamp except that the filament is designed to operate at a hig temperature. This lamp emits much more light than the general-ser lamp for the same wattage, but its life is much shorter, for exam 2 hr. for the smallest size to 10 hr. for the largest size.

The photoflash lamp is used to illuminate scenes for the takin

photographs, whereas the photoflood lamp is used for continuous illumination in the taking of moving pictures. The photoflood lamp is also used by commercial photographers for studio portrait work and by amateur photographers for interior photographs.

FIG. 32.—Photoflash lamp. (*Westinghouse Electric & Manufacturing Co.*)

79. The life of an incandescent lamp (*i.e.*, the useful life) is always understood to mean the total hours of burning before the candle power drops to 80 per cent of the initial, unless the lamp becomes useless because of broken filament or other cause prior to this. The total or burnout life of a lamp is the hours of burning before failure of the filament.

The average life of standard lamps for general lighting purposes is 750 hr. for some sizes and 1,000 hr. for other sizes when operated at their rated voltage. The life of a lamp is materially affected by the voltage impressed upon it. Operating a lamp at less than its rated voltage will prolong the life of the lamp, while operating at higher than rated voltage will shorten its life. This does not mean that it is good practice to operate lamps at less than their rated voltage. Decreasing the voltage on a lamp decreases the light given out by the lamp, but the percentage of decrease in light is much greater than the percentage of decrease in voltage, so that the efficiency of operation is much poorer. Figure 33 shows percentage variation in characteristics of Mazda lamps with variation from normal voltage. Consider a 120-volt lamp operating at 114 volts. The voltage impressed on the lamp is 95 per cent of rated voltage. From Fig. 33 the lumens emitted by the lamp will be reduced to 84 per cent of the rated value. Thus a 5 per cent reduction in voltage results in a 16 per cent reduction in light output (refer also to Sec. **84**).

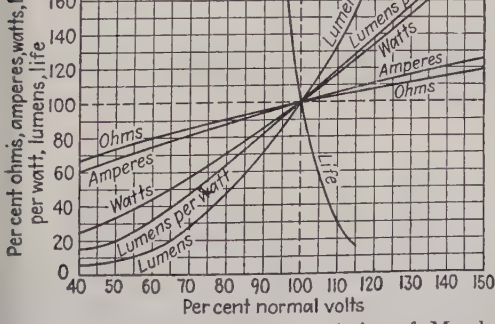


FIG. 33.—Variation in characteristics of Mazda lamps with voltage. (*General Electric Co.*)

80. Incandescent Mazda Lamps for 115-, 120-, and 125-volt General Lighting Service

(General Electric Co. and Westinghouse Electric & Manufacturing Co.)

Watts	Bulb	Std. pkg. quan.	Mazda B or Mazda C lamp	Rated initial lumens	Rated initial lumens per watt	Lumens per watt at 70% of rated life	Rated av. lab. life, hr.	Base	Max. over-all length, in.[a]	Av. light center length, in.[b]	Position of burning
				Clear-glass Bulb							
6	S-6, clear	120	B	40	6.6	....	1,500	Cand.	1 7/8	...	Any
7[c]	C-7, clear	120	B	50[d]	7.1	....	2,000	Cand.	2 1/8	...	Any
10	S-11, clear	120	B	80	8.0	....	1,500	Inter.	2 5/16	1 5/8	Any
10	S-14, clear	120	B	79	7.9[e]	7.2[e]	1,500	Med.	3 1/2	2 1/2	Any
150	PS-25, clear	60	C	2,600	17.3[f]	15.6[f]	750	Med.	6 15/16	5 1/4	Any[g]
200	PS-30, clear	60	C	3,650	18.3[f]	16.3[f]	750	Med.	8 1/16	6	Any[g]
300	PS-35, clear (750 hr.)	24	C	5,900	19.7[f]	17.3[f]	750	Med.	8 3/4	6	Any[g]
300	PS-35, clear (1,000 hr.)	24	C	5,650	18.9[f]	16.7[f]	1,000	Mog.	9 3/8	7	Any[g]
500	PS-40, clear	12	C	10,000	20.0[f]	16.8[f]	1,000	Mog.	9 3/4	7	Any[g]
750	PS-52, clear	6	C	15,500	20.6	17.2	1,000	Mog.	13 1/16	9 1/2	Any[g]
1,000	PS-52, clear	6	C	21,500	21.5	17.4	1,000	Mog.	13 1/16	9 1/2	Any[g]
1,500	PS-52, clear	6	C	33,000	22.0	17.6	1,000	Mog.	13 1/16	9 1/2	Any[g]
				Inside-frosted Bulb							
7[c]	C-7, white	120	B	.....	....	....	2,000	Cand.	2 1/8	...	Any
10	S-11, Ins. col. white	120	B	.....	....	....	2,000	Inter.	.....	...	Any
10	S-14, I.F.	120	B	78	7.8[e]	7.1[e]	1,500	Med.	3 1/2	2 1/2	Any
15	A-15, I.F.	120	B	141	9.4[e]	8.2[e]	1,200	Med.	3 1/16	2 3/8	Any
25	A-19, I.F.	120	B	260	10.4[e]	8.9[e]	1,000	Med.	3 15/16	2 1/2	Any
40	A-19, I.F.	120	C	465	11.7[f]	10.7[f]	1,000	Med.	4 1/4	2 7/8	Any[g]
50	A-19, I.F.	120	C	660	13.2[f]	12.5[f]	1,000	Med.	4 1/16	3 1/8	Any[g]
60	A-19, I.F.	120	C	835	13.9[f]	13.2[f]	1,000	Med.	4 7/16	3 1/8	Any[g]
75	A-21, I.F.	120	C	1,120	14.9[f]	13.5[f]	750	Med.	5 5/16	3 7/8	Any[g]
100	A-21, I.F.	120	C	1,630	16.3[f]	15.3[f]	750	Med.	5 5/16	3 7/8	Any[g]
150	PS-25, I.F.	60	C	2,600	17.3[f]	15.6[f]	750	Med.	6 15/16	5 1/4	Any[g]
200	PS-30, I.F.	60	C	3,700	18.4[f]	16.3[f]	750	Med.	8 1/16	6	Any[g]
300	PS-35, I.F. (750 hr.)	24	C	5,900	19.7[f]	17.3[f]	750	Med.	8 3/4	6	Any[g]
300	PS-35, I.F. (1,000 hr.)	24	C	5,650	18.8[f]	16.7[f]	1,000	Mog.	9 3/8	7	Any[g]
500	PS-40, I.F.	12	C	10,000	20.0[f]	16.9	1,000	Mog.	9 3/4	7	Any[g]
750	PS-52, I.F.	6	C	15,500	20.6	17.2	1,000	Mog.	13 1/16	9 1/2	Any[g]
1,000	PS-52, I.F.	6	C	21,500	21.5	17.3	1,000	Mog.	13 1/16	9 1/2	Any[g]

White-bowl Bulb											
150	PS-25, W.B.	60	C	.....	....	....	750	Med.	$6\frac{15}{16}$	$5\frac{1}{4}$	Base up
200	PS-30, W.B.	60	C	.....	....	....	750	Med.	$8\frac{1}{16}$	6	Base up
300	PS-35, W.B.	24	C	.....	....	....	1,000	Mog.	$9\frac{3}{8}$	7	Base up
500	PS-40, W.B.	12	C	.....	....	....	1,000	Mog.	$9\frac{3}{4}$	7	Base up
Silvered-bowl Bulb											
60	A-19, I.F., silv. bowl	120	C	.....	....	....	1,000	Med.	$4\frac{7}{16}$	$3\frac{1}{8}$	Any[g]
100	A-23, I.F., silv. bowl	120	C	.....	....	....	750	Med.	$6\frac{1}{16}$	$4\frac{3}{8}$	Any[g]
150[h]	PS-25, I.F., silv. bowl	60	C	.....	....	....	1,000	Med.	$6\frac{15}{16}$	$5\frac{1}{4}$	Base up
200[h]	PS-30, I.F., silv. bowl	60	C	.....	....	....	1,000	Med.	$8\frac{1}{16}$	6	Base up
300[h]	PS-35, I.F., silv. bowl	24	C	.....	....	....	1,000	Mog.	$9\frac{3}{8}$	7	Base up
500[h]	PS-40, I.F., silv. bowl	12	C	.....	....	....	1,000	Mog.	$9\frac{3}{4}$	7	Base up
Daylight Lamps											
60	A-19, day., I.F.	120	C	540[h]	....	....	1,000	Med.	$4\frac{7}{16}$	$3\frac{1}{8}$	Any[g]
100	A-23, day., I.F.	120	C	1,060[h]	....	....	750	Med.	$6\frac{1}{16}$	$4\frac{3}{8}$	Any[g]
150	PS-25, day., clear	60	C	1,600[h]	....	....	1,000	Med.	$6\frac{15}{16}$	$5\frac{1}{4}$	Any[g]
150	PS-25, day., I.F.	60	C	1,600[h]	....	....	1,000	Med.	$6\frac{15}{16}$	$5\frac{1}{4}$	Any[g]
200	PS-30, day., clear	60	C	2,350[h]	....	....	1,000	Med.	$8\frac{1}{16}$	6	Any[g]
200	PS-30, day, I.F.	60	C	2,350[h]	....	....	1,000	Med.	$8\frac{1}{16}$	6	Any[g]
300	PS-35, day., clear	24	C	3,650[h]	....	....	1,000	Mog.	$9\frac{3}{8}$	7	Any[g]
500	PS-40, day., clear	12	C	6,450[h]	....	....	1,000	Mog.	$9\frac{3}{4}$	7	Any[g]

Abbreviations: I.F. = Inside frosted Cand. = Candelabra W.B. = White bowl
Inter. = Intermediate Med. = Medium Mog. = Mogul

[a] Over-all length is measured from top of bulb to bottom of base.

[b] Light center length is measured from the center of the filament to bottom of screw bases; top of base pins or fins of bayonet or pre-focused bases; shoulder of post of mogul bipost bases; and bottom of bulb (base end) for medium bipost bases.

[c] Nominal watts. 110 to 125 volts (design volts 118).

[d] Approximate value.

[e] Lumens per watt listed are for 120-volt lamps only. For 115-volt lamps add 0.05 lumens per watt; for 125-volt lamps subtract 0.05 lumens per watt.

[f] Lumens per watt listed are for 120-volt lamps only. For 115-volt lamps add 0.15 lumens per watt; for 125-volt lamps subtract 0.15 lumens per watt.

[g] Will operate in any position, but lumen maintenance is best when burned vertically, base up, and lumens-per-watt values at 70 per cent of rated life apply to this burning position only.

[h] Silvered-bowl lamps should be used only in porcelain sockets and in fixtures so designed that the temperatures of the lamp and fixture do not exceed limits for satisfactory operation.

81. Incandescent Mazda Lamps for 115-, 120-, and 125-volt Special Lighting Service

(General Electric Co. and Westinghouse Electric & Manufacturing Co.)

Watts	Bulb	Std. pkg. quan.	Mazda B or Mazda C lamp	Rated initial lumens	Rated initial lumens per watt	Lumens per watt at 70% of rated life	Rated av. lab. life, hr.	Base	Max. over-all length, in.[a]	Av. light center length, in.[b]	Position of burning
					Lumiline Clear Lamps						
30	T-8, clear, lumiline	24	B	250	8.3	....	1,500	Disk	$17\frac{3}{4}$	...	Any
40	T-8, clear, lumiline	24	B	350	8.8	....	1,500	Disk	$11\frac{3}{4}$	...	Any
60	T-8, clear, lumiline	24	B	560	9.3	....	1,500	Disk	$17\frac{3}{4}$	...	Any
					Lumiline Inside-colored Lamps						
30	T-8, col.,[c] lumiline	24	B	.....	....	....	1,500	Disk	$17\frac{3}{4}$[c]	...	Any
40	T-8, col.,[c] lumiline	24	B	.....	....	....	1,500	Disk	$11\frac{3}{4}$[c]	...	Any
60	T-8, col.,[c] lumiline	24	B	.....	....	....	1,500	Disk	$17\frac{3}{4}$[c]	...	Any
					Tubular Lamps						
25	T-$6\frac{1}{2}$, clear	60	B	240	9.7	....	1,000	Inter.	$5\frac{1}{2}$	...	Any
25	T-10, clear	60	B	255	10.2[f]	8.6[f]	1,000	Med.	$5\frac{5}{8}$	...	Any
40	T-8, clear	24	B	410	10.3	8.7	1,000	Med.	$11\frac{7}{8}$	...	Any
40	T-10, clear	60	B	425	10.6	....	1,000	Med.	$5\frac{5}{8}$	...	Any
					Inside-colored Bulbs						
10	S-14, colored[g]	120	B	.....	....	....	1,500	Med.	$3\frac{1}{2}$	...	Any
25	A-19 colored[h]	120	B	.....	....	....	1,000	Med.	$3\frac{15}{16}$	...	Any

Incandescent Mazda Lamps for 115-, 120-, and 125-volt Special Lighting Service (*Continued*)

Watts	Bulb	Std. pkg. qty.	Mazda B or Mazda C lamp	Rated initial lumens	Rated initial lumens per watt	Lumens per watt at 70% of rated life	Rated av. lab. life, hr.	Base	Max. over-all length, in.[a]	Av. light center length, in.[b]	Position of burning
					Outside-colored Bulbs						
7½[d]	G-11, white, red	120	B	.....	....	....	1,400	Med.	2¼	...	Any
25[d]	G-18½, wh.	120	B	.....	....	....	750	Med.	3 9/16	...	Any
25[d]	A-19, F.T., amb., red, green, blue, ivory	120	B	.....	....	....	....	Med.	.....	...	Any
					Flame-type Bulbs						
15[d]	F-10, F.T., wh., ivory	60	B	.....	....	....	750	Cand.	3 1/16	...	Any
25[d]	F-15, F.T., wh., ivory	120	B	.....	....	....	750	Med.	4½	...	Any
					Rough-service Lamps						
50	A-19, I.F., rough serv.	120	B	455	9.1[f]	7.6[f]	1,000	Med.	3 5/16	2½	Any
50	A-19, cl., vibration	120	B	555	11.1[f]	8.4[f]	1,000	Med.	3 5/16	2½	Any but horiz.
100	A-23, I.F., rough serv.	120	C	1,200	12.0[f]	10.3[f]	1,000	Med.	6 1/16	4⅜	Any
100	A-23, I.F., vibration	120	C	1,300	13.0	....	1,000	Med.	6 1/16	4⅜	Any but horiz.

[a] Over-all length is measured from top of bulb to bottom of base.

[b] Light center length is measured from the center of the filament to bottom of screw bases; top of base pins or fins of bayonet or prefocused bases; shoulder of post of mogul bipost bases; and bottom of bulb (base end) for medium bipost bases.

[c] Average over-all length.

[d] Outside-coated lamps not recommended for outdoor use.

[e] Inside frosted or colored white, straw, orange, moonlight blue, emerald, and surprise pink.

[f] Lumens per watt listed are for 120-volt lamps only. For 115-volt lamps add 0.05 lumens per watt; for 125-volt lamps subtract 0.05 lumens per watt.

[g] Inside colored in red, blue, green, yellow, amber-orange, and old rose.

[h] Inside colored in red, blue, green, yellow, amber-orange, flame tint, ivory, and old rose.

82. Incandescent Mazda Lamps for Miscellaneous Lighting Service

Watts	Volts	Bulb	Std. pkg. quan.	Mazda B or C lamp	Rated initial lumens	Rated initial lumens per watt	Lumens per watt at 70% of rated life	Rated av. lab. life, hr.	Amp.	Base	Max. over-all length, in.[a]	Av. light center length, in.[b]	Position of burning
Traffic-signal Service													
60	.....	A-21, clear	120	C	665	11.1	....	2,000	.....	Med.	$4\frac{7}{16}$	$2\frac{7}{16}$	Base down or horiz.
Three-lite Lamps													
50	.....	PS-25, I.F., three-lite	60	C	620	12.4	....	750	.....	Three-contact Mogul	$5\frac{5}{16}$	$3\frac{7}{8}$	Base down
100	.....				1,490	14.9	....						
150					2,110	14.1	....						
50		PS-25, I.F., three-lite	60	C	590	11.8		1,000	.....	Three-contact Mogul	$6\frac{13}{16}$	5	Any
100	.....				1,420	14.2	....						
150					2,010	13.4							
100		G-30, I.F., indirect, three-lite	24	C	1,410	13.6	....	1,000	.....	Three-contact Mogul	$6\frac{3}{4}$	$3\frac{3}{4}$	Base down
200	.....				3,350	17.0	....						
300					4,760	15.9	....						
Showcase Reflector Lamps													
25	110	T-10, I.F.	60	C	230	....	....	1,000	.....	Med.	$5\frac{5}{8}$	.....	Any
40	115	T-10, I.F.	60	C	.....	....	....	1,000	.....	Med.	$5\frac{5}{8}$	.....	Any
	120												
High-voltage Service—230 and 250 Volts													
25	.....	A-19, I.F.	120	B	215	8.7[c]	8.0[c]	1,000	.....	Med.	$3\frac{15}{16}$	$2\frac{1}{2}$	Any
50	.....	A-19, I.F.	120	B	480	9.6[c]	8.2[c]	1,000	.....	Med.	$3\frac{15}{16}$	$2\frac{1}{2}$	Any
100	.....	A-23, I.F.	120	C	1,240	12.5[d]	11.6[d]	1,000	.....	Med.	$6\frac{1}{16}$	$4\frac{3}{8}$	Any[e]
200	.....	PS-30, clear	60	C	3,000	14.9[d]	13.7[d]	1,000	.....	Med.	$8\frac{1}{16}$	6	Any[e]
200	.....	PS-30, I.F.	60	C	3,000	14.9[d]	14.5[d]	1,000	.....	Med.	$8\frac{1}{16}$	6	Any[e]
300	.....	PS-35, clear	24	C	4,850	16.2[d]	14.0[d]	1,000	.....	Mog.	$9\frac{3}{8}$	7	Any[e]
500	.....	PS-40, clear	12	C	8,800	17.6[d]	16.0[d]	1,000	.....	Mog.	$9\frac{3}{4}$	7	Any[e]
750	.....	PS-52, clear	6	C	13,600	18.6[d]	16.2[d]	1,000	.....	Mog.	$13\frac{1}{16}$	$9\frac{1}{2}$	Any[e]
1,000	.....	PS-52, clear	6	C	19,100	19.1[d]	16.6[d]	1,000	.....	Mog.	$13\frac{1}{16}$	$9\frac{1}{2}$	Any[e]

Country-home Service—28–32 Volts

15	28–32	A-17, I.F.	120	C	179	11.9	....	1,000	.....	Med.	$3\frac{5}{8}$	$2\frac{3}{8}$	Any[e]
25	28–32	A-19, I.F.	120	C	350	14.1	....	1,000	.....	Med.	$3^{15}/_{16}$	$2\frac{1}{2}$	Any[e]
50	28–32	A-21, I.F.	120	C	820	16.4	....	1,000	.....	Med.	$4^{15}/_{16}$	$3\frac{3}{8}$	Any[e]
100	28–32	A-23, I.F.	120	C	1,850	18.5	....	1,000	.....	Med.	$6\frac{1}{16}$	$4\frac{3}{8}$	Any[e]

Street-railway Service

25	30	A-19, I.F.	120	C	393	13.2	....	2,000	1.0	Med.	$3^{15}/_{16}$	$2\frac{1}{2}$	Any[e]
50	30	A-21, I.F.	120	C	705	14.7	....	2,000	1.6	Med.	$4\frac{7}{16}$	$2\frac{7}{8}$	Any[e]
15[f]		S-14, clear	120	B	139	9.3	....	1,000	.....	Med.	$3\frac{1}{2}$	$2\frac{1}{2}$	Any
36[f]		A-19, clear, headlt	120	B	375	9.5	....	1,000	0.342	Med.	$3^{15}/_{16}$	$2^{3}/_{16}$	Any
56[f]	115	A-21, I.F.	120	B	365	9.3	....	2,000	0.342	Med.	$4\frac{7}{16}$	$2\frac{7}{8}$	Any[h]
56[f]	120	P-25, clear, headlt	60	B	620[g]	10.4	....	2,000	0.519	Med.	$4\frac{7}{16}$	$2\frac{7}{8}$	Any[h]
94[f]	125	P-25, clear, headlt	60	B	885[g]	8.9	....	1,000	0.519	Med.	$4\frac{3}{4}$	$2^{1}/_{16}$	Any
101		A-23, I.F.	120	C	1,150	11.5	....	1,000	0.863	Med.	$4\frac{3}{4}$	$2^{1}/_{16}$	Any
201		PS-30, clear	60	C	3,100	15.4	....	1,500	.....	Med.	$6\frac{1}{16}$	$4\frac{3}{8}$	Any[e]
301		PS-35, clear	24	C	5,000	16.6	....	1,000	.....	Med.	$8^{1}/_{16}$	6	Any[e]
								1,000	.....	Mog.	$9\frac{3}{8}$	7	Any[e]

Aviation Service

240	12	A-19, clear	12	C	5,750	24.0	....	100	.....	Md. pf.	$4\frac{1}{8}$	$1\frac{3}{4}$[i]	[j]
420	12	G-25, clear	12	C	10,500	25.0	....	100	.....	Mg. pf.	$5^{3}/_{16}$	$1^{11}/_{16}$[i]	[j]
500	115 / 120 / 125	T-20, clear	12	C	9,000	18.0	....	800	.....	Mg.	$9^{1}/_{16}$	$4\frac{3}{4}$[i]	Base down
1,000	115 / 120	T-20, clear	12	C	20,500	20.5	....	500	.....	Mg. bip.	$9\frac{1}{2}$	4[k]	Base down
1,500	32	T-24, clear	12	C	42,000	28.0	....	100	.....	Mg. bip.	$10\frac{1}{2}$	4[k]	Base down
3,000	32	T-32, clear	6	C	88,500	29.5	....	100	.....	Mg. bip.	14	$5\frac{3}{4}$[k]	Base down

[a] Over-all length is measured from top of bulb to bottom of base.

[b] Light center length is measured from the center of the filament to bottom of screw bases; top of base pins or fins of bayonet or prefocused bases; shoulder of post of mogul bipost bases; and bottom of bulb (base end) for medium bipost bases.

[c] Lumens per watt listed are for 230-volt lamps only.

[d] Lumens per watt listed are for 230-volt lamps only.

[e] Will operate in any position, but lumen maintenance is best when burned vertically, base up, and lumens per watt values at 70 per cent of rated life apply to this burning position only.

[f] Nominal watts. The actual watts are determined by multiplying the volts by the amperes (the amperes are the same for all voltages).

[g] The lumens given cover only lamps of 115 volts. The lumens for other lamps are in proportion to the volts.

[h] This lamp, if burned horizontally, will not give as good service as when burned in a vertical position.

[i] The light center length of this lamp is the distance from center of light source to top of base fin.

[j] Can be burned in any position except within 45 deg. of vertically, base up.

[k] The light center length of this lamp is exclusive of base prongs, the base prong being the small-diameter part of metal post.

Incandescent Mazda Lamps for Miscellaneous Lighting Service (*Continued*)

Watts	Volts	Bulb	Std. pkg. quan.	Mazda B or C lamp	Rated initial lumens	Rated initial lumens per watt	Lumens per watt at 70% of rated life	Rated av. lab. life, hr.	Base	Max. over-all length, in.[a]	Av. light center length, in.[b]	Position of burning
Aviation Service (*Continued*)												
5,000	115	T-64, clear	1	C	164,000	32.7	....	75	Mg. bip.	13⅜	6½[k]	Base down
10,000	120											
	125	G-96, clear	1	C	325,000	32.7	....	75	Mg. bip.	17⅜	10[k]	Base down
Train and Locomotive Service												
15	30	A-17, I.F.	120	C	179	11.9	11.2	1,000	Med.	3⅝	2⅜	Any[e]
15	34	S-14, clear, cab	120	B	139	9.3	....	1,000	Med.	3½	2½	Any
15	60	A-17, I.F.	120	B	150	10.0	....	1,000	Med.	3⅝	2⅜	Any
25	30	A-19, I.F.	120	C	350	14.1	13.2	1,000	Med.	3 15/16	2½	Any[e]
25	60	A-19, I.F.	120	C	290	11.6	....	1,000	Med.	3 15/16	2½	Any[e]
50	30	A-21, I.F.	120	C	820	16.4	15.4	1,000	Med.	4 15/16	3⅜	Any[e]
50	60	A-21, I.F.	120	C	710	14.2	....	1,000	Med.	4 15/16	3⅜	Any[e]
100	30	A-23, I.F.	120	C	1,850	18.5	16.9	1,000	Med.	6 1/16	4⅜	Any[e]
100	32	PS-25, clear, headlt	60	C	1,570	15.2	....	500	Med.	4¾	3	[f]
100	60	A-23, I.F.	120	C	1,650	16.5	....	1,000	Med.	6 1/16	4⅜	Any[e]
250	32	PS-25, clear, headlt	60	C	4,500	18.0	....	500	Med.	4¾	3	[f]

Incandescent Mazda Lamps for Miscellaneous Lighting Service (*Continued*)

Watts	Bulb	Std. pkg. quan.	Mazda B or C lamp	Rated initial lumens	Rated initial lumens per watt	Rated av. lab. life, hr.	Base	Max. over-all length, in.[a]	Av. light center length, in.[b]	Light-source dimensions, mm.		Position of burning
										Width	Height	
Projection and Stereopticon Service—115, 120, and 125 Volts												
100	T-8, clear	24	C	1,920	19.2	50	S.C. bay.	3 1/8	1 3/8 [l]	5.6 [m]	5.3 [m]	Base down or can be burned within 25 deg. of vertical, base down, without materially affecting its performance
150	T-8, clear	24	C	3,300	22	25	S.C. bay.	3 5/8	1 3/8 [l]	5.5 [m]	6.4 [m]	
200 [n]	T-8, clear	24	C	4,700	23.5	25	S.C. bay	3 5/8	1 3/8 [l]	6.2 [m]	6.4 [m]	
200	T-10, clear	24	C	4,200	21.2	50	Med. pf.	5 3/4	2 3/16 [l]	7.9 [m]	7.9 [m]	
300 [n]	T-10, clear	24	C	.....	....	25	Md. pf.	5 3/4	2 3/16 [l]	7.0 [m]	9.0 [m]	
500 [n]	T-10, clear	24	C	.....	....	25	Md. pf.	5 3/4	2 3/16 [l]	8.2 [m]	8.3 [m]	
500	T-20, clear	6	C	13,200	26.5	50	Md. pf.	5 3/4	2 3/16 [l]	14.0 [m]	12.0 [m]	
750 [n]	T-12, clear	24	C	.....	....	25	Md. pf.	5 3/4	2 3/16 [l]	9.8 [m]	10.0 [m]	
1,000 [n]	T-12, clear	24	C	.....	....	10	Md. pf.	5 3/4	2 3/16 [l]	10.2 [m]	10.2 [m]	
1,000	T-20, clear	6	C	28,000	28.0	50	Mg. pf.	9 1/2	3 7/16	14.9 [m]	14.5 [m]	
Spotlight and Floodlight Service—115, 120, and 125 Volts												
100	P-25, clear, spot	60	C	1,360	13.6	200	Med.	4 3/4	3	8	7	Any position from vertical, base down, to horizontal [o]
250	G-30, clear, spot	24	C	4,400	17.7	200	Med.	5 1/8	3	10	8	
250	G-30, clear, flood	24	C	3,750	15.1	800	Med.	5 1/8	3	12	9	
400	G-30, clear, spot	24	C	8,000	20.0	200	Med.	5 1/8	3	11	9	
500	G-40, clear, flood	12	C	8,800	17.6	800	Mog.	7 1/16	4 1/4	13	10	
1,000	G-40, clear, spot	12	C	22,500	22.5	200	Mog.	7 1/16	4 1/4	14	13	
1,000	G-40, clear, flood	12	C	19,500	19.5	800	Mog.	8	5 1/4	16	15	

Abbreviations: Md. pf. = Medium prefocus
S.C. bay. = Single contact bayonet

[a] Over-all length is measured from top of bulb to bottom of base.

[b] Light center length is measured from the center of the filament to bottom of screw bases; top of base pins or fins of bayonet or prefocused bases; shoulder of post of mogul bipost bases; and bottom of bulb (base end) for medium bipost bases.

[e] Will operate in any position, but lumen maintenance is best when burned vertically base up, and lumens per watt values at 70 per cent of rated life apply to this burning position only.

[f] Can be burned in any position except within 45 deg. of vertically, base up.

[k] The light center length of this lamp is exclusive of base prongs, the base prong being the small-diameter part of metal post.

[l] The light center length of this lamp is the distance from center of light source to top of base fin.

[m] Approximate average for 115 volts. Dimensions for other standard voltages will be supplied on request.

[n] This lamp should be used only in equipment that provides adequate forced cooling.

[o] Unsatisfactory lamp operation is likely to occur in burning positions between horizontal and base up, particularly between 45 deg. from base up, and base up.

Street Series Service

All street series lamps are gas-filled and have clear bulbs. All standard street series lamps have an average rated laboratory life of 2,000 hr.; because of the severity of street-lighting service, the average service life of street series lamps even under good operating conditions is of the order of 25 per cent less than the average laboratory life.

Amp.	Rated initial lumens	Bulb	Std. pkg. quan.	Initial volts	Initial watts	Rated initial lumens per watt	% lumens at 70 per cent of rated life	Base	Max. over-all length, in.[a]	Position of burning[b]	Av. light center length, in.
6.6	1,000	PS-25	60	9.4	61.5	16.2	100	Mog.	7⅛	Any[c]	5⅜
6.6	2,500	PS-35	24	21.7	143	17.5	100	Mog.	9⅜	Any[c]	7
6.6	4,000	PS-35	24	31.9	210.0	19.0	98	Mog.	9⅜	Any[c]	7
15	4,000	PS-35	24	13.5	205.0	19.7	95	Mog.	9⅜	Base up Base down	7 6¼
6.6	6,000	PS-40	12	46.9	310.0	19.4	95	Mog.	9¾	Any	7
20	6,000	PS-40	12	14.7	295.0	20.4	94	Mog.	9¾	Base up Base down	7 6¼
20	10,000	PS-40	12	24.3	485.0	20.6	91	Mog.	9¾	Base up Base down	7 6¼
20	15,000	PS-40	12	35.7	715.0	21.0	85	Mog.	9¾	Base up Base down	7 6¼

[a] Over-all length is measured from top of bulb to bottom of base.

[b] Light center length is measured from the center of the filament to bottom of screw bases; top of base pins or fins of bayonet or prefocused bases; shoulder of post of mogul bipost bases; and bottom of bulb (base end) for medium bipost bases.

[c] Will operate in any position, but lumen maintenance is best when burned vertically, base up, and the percentage of lumens at 70 per cent of rated life applies to this burning position only.

Projector and Reflector Lamps—115, 120, and 125 Volts

Watts	Bulb	Std. pkg. quan.	Mazda B or Mazda C lamp	Initial zone lumens	Initial max. beam candlepower[a]	Rated av. lab. life, hr.	Base	Max. over-all length, in.[b]	Position of burning
Projector Spot Lamp									
150[c]	PAR-38	12	C	990(0–15 deg.)	10,500	1,000	Med. skt.	5 5/16	Any
Projector Flood Lamp									
150[c]	PAR-38	12	C	1,150(0–30 deg.)	2,500	1,000	Med. skt.	5 5/16	Any
Reflector Spot Lamps[d]									
150	R-40, Light I.F.	12	C	700(0–15 deg.)	7,000	1,000	Med.	6 1/2	Any
300[c]	R-40, Light I.F.	12	C	1,460(0–15 deg.)	16,000	1,000	Med.	6 1/2	Any
Reflector Flood Lamps[d]									
150	R-40, I.F.	12	C	700(0–30 deg.)	1,200	1,000	Med.	6 1/2	Any
300[c]	R-40, I.F.	12	C	1,620(0–30 deg.)	3,000	1,000	Med.	6 1/2	Any

[a] Readings taken at distance of 10 ft.
[b] Over-all length is measured from top of bulb to bottom of base.
[c] Should be burned only in porcelain sockets.
[d] May not give satisfactory performance if any accessory lighting equipment is attached to, or touches, the glass bulb.

Photographic Service

Lamp designation	Voltage range for operation	Approx. watts	Rated life at 115 volts, hr.	Flash duration at ½ peak (milliseconds)	Approx. lumen-seconds	Approx. peak lumens	Approx. mean color temp., °K	Bulb	Max. over-all length, in.	Base	Packing	
											Carton	Case
Photoflash Lamps—Clear Bulb												
Speed Midget "SM"	3[a]	.....	...	5	4,500	820,000	3300	B-11	2 5/8	S. C. bay.	8	120
Synchro-Press No. 5	3[a]	.....	...	13	16,000	1,100,000	3800	B-11	2 5/8	S. C. bay.	8	120
Synchro-Press No. 5B	3[a]	.....	...	13	7,000	480,000	6000	B-11	2 5/8	S. C. bay.	8	120
Focal Plane No. 6	3[a]	.....	...	30	15,000	620,000	3800	B-11	2 5/8	S. C. bay.	8	120
Synchro-Press No. 11	3[a]	.....	...	12	28,000	2,200,000	3800	A-15	4	Med.	8	120
Synchro-Press No. 22B	3–125	.....	...	14	60,000	3,800,000	6000	A-19	5	Med.	6	120
Synchro-Press No. 22	3–125	.....	...	14	26,000	1,650,000	3800	A-19	5	Med.	6	120
Focal Plane No. 31	3[a]	.....	...	53	75,000	1,400,000	3800	A-21	5 3/8	Med.	6	60
Photoflash No. 50	3–125	.....	...	17	93,000	4,800,000	3800	A-21	5 3/8	Med.	6	60
Synchro-Press No. 50B	3–125	.....	...	17	40,000	2,000,000	6000	A-21	5 3/8	Med.	6	60
Photoflood Lamps—Inside-frosted Bulb												
Photoflood No. 1	115–120	250	3	..	.....	8,650	3400	A-21	4 15/16	Med.	6	60
Photoflood No. 2	115–120	500	6	..	.....	17,000	3400	PS-25	6 15/16	Med.	6	24
Photoflood No. RFL2	115–120	500	6	..	.....	[b]	3400	R-40	6 1/2	Med.	1	12
Photospot No. RSP2	115–120	500	6	..	.....	50,000[c]	3400	R-40	6 1/2	Med.	1	12
Photoflood No. 4	115–120	1,000	10	..	.....	33,500	3400	PS-35	9 3/8	Mogul	1	24
Photographic Enlarger Lamps—White Bulb												
Photo. Enlarger No. 111	115–125	75	25	..	.....	1,125	....	S-11[d]	2 3/8	S. C. bay.	6	120
Photo. Enlarger No. 211	115–125	75	100	..	.....	1,300	....	A-21	4 15/16	Med.	6	60
Photo. Enlarger No. 212	115–125	150	100	..	.....	3,100	....	A-21	4 15/16	Med.	6	60
Photo. Enlarger No. 213	115–125	250	3	..	.....	8,000	....	A-21	4 15/16	Med.	6	60
Photo. Enlarger No. 302	115–125	500	100	..	.....	11,600	....	PS-30	8 3/16	Med.	1	24
Three-lite Enlarger	115	50 100 150	100	..	.....	.....	....	A-21	4 3/4	[e]	6	60

Daylight blue bulb Photoflood lamps—No. B1, No. B2, No. B4—to supplement daylight for color photography.

[a] Flash with two or more dry cells only.

[b] Light concentrated in photo-effective zone. Equivalent to No. 2 photoflood in good reflector.

[c] Approximate Beam Candlepower.

[d] Burning position—Base down or horizontal. Base pins in plane of filament. Use only equipment that provides adequate ventilation.

[e] Three-contact medium screw base. Requires special socket.

83. Voltage of Lamps.—Most sizes and types of incandescent lamps are regularly made and stocked for three different voltage ratings: 115, 120, and 125 volts. Certain sizes are also made for other voltages as listed in Table 82. The correct voltage rating should be considered carefully when ordering incandescent lamps. From Sec. **79** it is apparent that it is important not to operate lamps at less than their rated voltage. In fact if the desired number of lumens falls halfway between two standard sizes of lamps it is usually cheaper to use the smaller size lamp at about 5 volts overvoltage than to use the larger size at rated voltage.

Example.—The desired number of lumens per lamp is 4,500. Compare the cost of using 300-watt, 120-volt lamps at rated voltage with using 200-watt, 115-volt lamps at 120 volts. Assume that the increment cost of power (the cost of the lowest block at which the power will be billed) is 1 ct. per kw.-hr., that a 200-watt lamp cost $0.20 and a 300-watt lamp cost $0.50 and that the demand charge is $1.50 per kw. per month.

The 200-watt lamp will be operated at $(^{120}/_{115}) \times 100$ per cent = 104.2 per cent of rated voltage and will therefore draw approximately 104 per cent of rated current and consume $(104 \text{ per cent})^2 = 108.5$ per cent of rated watts. The life will be shortened (from Fig. 33) to 60 per cent of the normal life. Assume 1,500 hr. of use per year.

Item	300-watt lamp at rated voltage	200-watt lamp at 104 per cent of rated voltage
Annual cost of lamps	$1\frac{1}{2} \times \$0.50 = \$0.75$	$3\frac{1}{3} \times \$0.20 = \$0.67$
Cost of energy for 1,500 hr	$\frac{300}{1,000} \times 1,500 \times 0.01 = \$4.50$	$\frac{200}{1,000} \times 1.085 \times 1,500 \times 0.01 = \$3.25$
Demand charge for 12 months	$0.3 \times \$1.50 \times 12 = \$5.40$	$0.217 \times \$1.50 \times 12 = \$3.90$
Total	$10.65	$7.82
Lumens	5,650	$1.16 \times 3,650 = 4,235$

Therefore, the smaller sized lamp will produce 4,235/4,500 or about 94 per cent of the desired lumens, which would probably be sufficient, at a saving of $2.83 per year per fixture over using the larger sized lamp. In addition, the installation cost could be made less owing to the use of smaller sized fixtures, the 200-watt size costing about 15 per cent less than the 300-watt size.

FLUORESCENT LAMPS

84. The fluorescent lamp (Fig. 34) is an electronic device (see Sec. **1** of Div. 6). It functions through conduction in a gas. It consists of a long straight or circular tube containing a drop of mercury and a small amount of argon gas with electrodes sealed into each end. Both electrodes are so constructed that they can function as cathodes (emitters of electrons into the enclosure). The lamp will therefore conduct in either direction and pass alternating current. The inside surface of the tube is coated with a fluorescent chemical (Sec. **86**). Fluorescent lamps may be constructed with hot or cold cathodes (see Sec. **11** of Div. 6). Hot cathodes are con-

structed of coated tungsten filaments wound in coil form. Cold cathodes are made of iron, shaped in thimblelike form in order to give a large emitting area. Cold cathodes require a higher voltage drop across the lamp for the production of the emission. Lamps with cold cathodes will consequently not have such high efficiency, *i.e.*, lumens per watt. However, because of their inherently long life, cold-cathode lamps are advantageous for special custom-built shapes and patterns and for applications where it is difficult to replace the lamp. Most general-purpose lamps are operated with hot cathodes. Some of the general-purpose lamps are started with cold cathodes by applying a sufficiently high voltage to produce electric-field emission. However, after the lamp has conducted for only a fraction of a second, the impinging arc will heat a few of the segments of the cathode filament wire to a red-hot tempera-

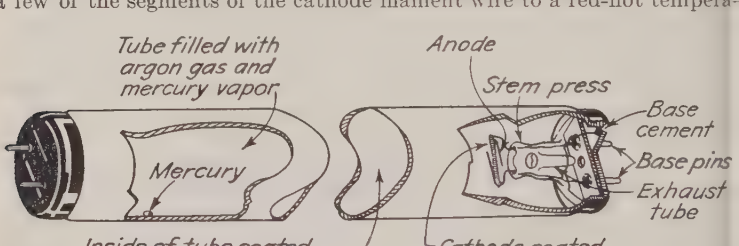


FIG. 34.—Fluorescent-lamp construction. (*General Electric Co.*)

ture. The cathode then produces thermionic emission, and the lamp continues to function under hot-cathode operation.

85. Operation of Fluorescent Lamps.—Although all general-purpose fluorescent lamps operate with hot cathodes, they are started with either hot-cathode or cold-cathode action. Hot-cathode starting is called preheat starting, and cold-cathode starting is called instant starting since the lamps light almost instantaneously upon the closing of the lamp circuit. The preheat-start lamps are constructed with bipin bases at each end, as shown in Fig. 34. The instant-start lamps are constructed with either bipin or single-pin bases at each end. In either construction the filament of instant-start lamps is short-circuited in the base. The only purpose of making some of the instant-start lamps with bipin bases is so that these lamps may be used in the conventional type of bipin lampholder which is employed for preheat-start lamps. However, the bipin instant-start lamps will not operate on the same ballast circuits as those employed for preheat lamps.

The principles of operation of a preheat-start fluorescent lamp may be understood from a study of the schematic diagram of Fig. 35. This figure shows the simplest connections that it is possible to employ for operation of these lamps. A reactor, connected in series with the lamp is always required for starting and stabilizing the operation. Switch *S* is

an automatic starting switch, or starter, as it is called. This switch is in its closed position when no current is passing through the circuit. When the circuit switch is closed, the two filaments are connected in series through switch S to the supply voltage. No current will flow through the lamp between the filaments, since this path is short-circuited by switch S and also the argon gas is not in a conducting state when the filaments are cold. Current will flow through the filaments, heating them to the proper temperature and vaporizing the mercury. After a few seconds, switch S automatically opens, breaking the circuit and causing the reactor to produce a high voltage between the two filaments. This strikes an arc through the argon gas and the mercury vapor, the purpose of the argon being to facilitate the starting of the arc. The mercury-vapor arc produces a large amount of ultraviolet-light radiation, which impinges on the fluorescent chemicals on the inside of the tube, causing them to fluoresce and emit a brilliant light, the color of which may be pink, gold, green, or blue depending upon the chemical used (see Table 86). By combining chemicals, a white light or a blue daylight may be obtained.

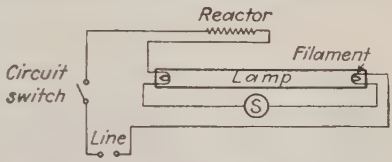


FIG. 35.—Circuit for fluorescent lamp.

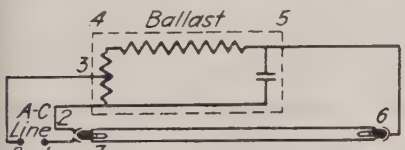


FIG. 36.—Circuit for instant-start fluorescent lamp.

The simplest circuit that it is possible to employ for an instant-start lamp is shown in Fig. 36. A ballast reactor is always required, as with the preheat-start lamp. Since the lamp starts with cold cathodes, no starter switch is required. However, the circuit must be so arranged that (1) a high voltage will be impressed across the lamp when the lamp circuit is closed and (2) the voltage across the lamp is reduced to its normal operating value as soon as conduction takes place and the lamp is started. The simple circuit of Fig. 36 will perform these two functions. At the instant that the circuit to the lamp is closed, there is no conduction through the lamp, and terminals 6 and 7 are open-circuited. The reactor 2-3-4 will act as a step-up autotransformer and produce from 6 to 7 a voltage of a magnitude considerably greater than the line voltage from 1 to 8. This high voltage will strike an arc through the argon gas and start conduction. As soon as the lamp conducts, the self-inductance of the ballast reactor 4-5 reduces the voltage across the lamp to normal operating voltage. A fraction of a second after the arc is struck, the filaments are heated sufficiently by the arc to produce thermionic emission. The production of visible light in the instant-start lamp is the

same as that described in the preceding paragraph for the preheat-start lamp.

86. Data on Fluorescent Chemicals

(In addition to the phosphor, manganese is usually present as an activator)

Phosphor	Lamp color	Exciting range,[a]	Sensitivity peak	Emitted range	Emitted peak
Calcium tungstate....	Blue	2,200–3,000[b]	2,720	3,100–7,000	4,400
Magnesium tungstate.	Blue-white	2,200–3,200	2,850	3,600–7,200	4,800
Zinc silicate.....	Green	2,200–2,960	2,537	4,600–6,400	5,250
Zinc beryllium silicate.	Yellow-white	2,200–3,000	2,537	4,800–7,500	5,950
Cadmium silicate.....	Yellow-pink	2,200–3,200	2,400	4,800–7,400	5,950
Cadmium borate.....	Pink	2,200–3,600	2,500	5,200–7,500	6,150
360 BL phosphor.....	Blue ultra	2,200–3,200	2,500–2,800	3,200–4,500	3,600
"E" phosphor.....	Blue ultra	2,200–2,650	2,475	2,700–4,000	3,250

[a] 2,200 A is lower limit of measurements.

[b] All values are given in Angstrom units. The Angstrom unit, used to measure wave length of radiation, is 1/100,000,000 cm. in length.

87. Types of Fluorescent Lamps.—The types of fluorescent lamps which have been developed up to the present time are:

1. Visible-light lamps.
   - *a.* Standard line.
   - *b.* Slimline.
   - *c.* Circline.
2. Ultraviolet lamps (see Sec. **134**).

Standard-line lamps comprise the line of fluorescent lamps which are constructed with the same general proportions as those of the first commercial fluorescent lamps introduced in 1938. They have long straight tubes with diameters varying from $\frac{5}{8}$ in. for the 6-watt size to $2\frac{5}{8}$ in. for the 100-watt size. The length of the lamps varies from 9 in. for the 6-watt size to 60 in. for the 100-watt size. Most of the lamps in this line are of the preheat-start type, although a few lamps are made in the instant-start type with bipin bases. The base pins are short-circuited inside the end cap, and the lamps will not operate on preheat ballast circuits.

Slimline lamps comprise the line of fluorescent lamps which are constructed with proportions somewhat different from those of the lamps of the standard line. Like the standard-line lamps, they have long straight tubes, but they are thinner in proportion to their length. The diameter of the tubes varies from $\frac{3}{4}$ in. for the 16-watt size to 1 in. for the 51-watt size. They supplement and extend the available sizes and dimensions of fluorescent lamps so that more flexibility is given to the design of fluores-

cent-lighting installations. The slimline lamps have lower values of light emitted per foot of lamp length than the standard-line, so that the lamps have lower values of brightness. All slimline lamps are of the instant-start type and are made with single-pin bases.

Circline lamps are the latest addition to the fluorescent-lamp family. The tube of the circline lamp is formed in a circle, as shown in Fig. 36*A*. The circline lamp extends the application of fluorescent lamps to a wider

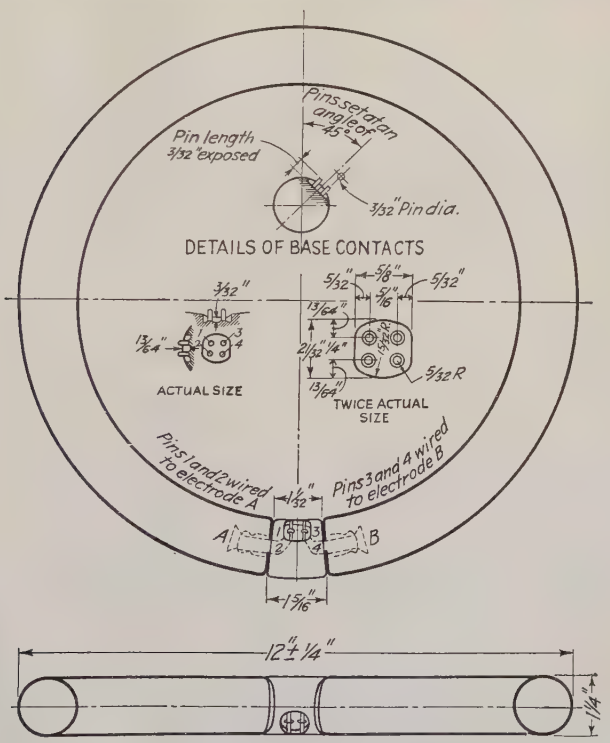


FIG. 36*A*.—Circline fluorescent lamp. (*Westinghouse Electric & Manufacturing Co.*)

field. They will adapt the fluorescent lamp to portable lamps and many new luminaire designs. The circline lamps are all of the preheat-start type. The four terminals are brought out at the junction point in the circle of the two ends of the tube. The lamps are equipped with a four-prong base. At the present time only one circline lamp is available. It has a tube diameter of 1¼ in. and an outside diameter of the circle formed by the tube of 12 in. Circline lamps of 8 and 16 in. outside diameters will shortly be available. They will have watt ratings of approximately 20 and 40 watts, respectively.

88. Standard Line Lamps

Characteristic	9-in., T-5	12-in., T-5	21-in., T-5	15-in., T-12	18-in., T-8	18-in., T-12	24-in., T-12		36-in., T-8		48-in , T-12		60-in., T-17	60-in., T-17	
Nominal lamp wattage[a]	6	8	13	14	15	15	20		30		40		40	100	
Approximate lamp amperage	0.15	0.16	0.16	0.37	0.30	0.33	0.35		0.34		0.41		0.40	1.45	
Approximate lamp voltage	40	57	100	41	56	48	62		103		108		110	72	
Diameter, in	5/8	5/8	5/8	1½	1	1½	1½		1		1½		2⅛	2⅛	
Rated average life, hr.[b]	1,500	1,500	1,500	2,000	2,500	2,500	2,500		4,000		4,000		2,500	4,500	
Burning hours per start	3	3	3	3	3	3	3		6		6		3	6	
Color	Lumens[c]	Lumens[c]	Lumens[c]	Lumens[c]	Lumens[c]	Lumens[c]	Lumens[c]	Foot-lamberts	Lumens[c]	Foot-lamberts	Lumens[c]	Foot-lamberts	Lumens[c]	Lumens[c]	Foot-lamberts
White	210	330	585	490	615	600	920	1,450	1,470	2,260	2,300	1,750	.....	4,200	1,850
Daylight	186	295	520	435	585	540	800	1,260	1,350	2,080	1,920	1,470	.....	3,900	1,710
Soft white	...	...	...	380	480	465	700	1,260	1,170	1,800	1,720	1,310	.....	3,300	1,450
4500° white	...	...	...	...	...	...	...	.....	.....	.....	2,100	1,610	2,100	4,000	1,760
Pink	...	...	...	...	300	...	440	800	750	1,300					
Red	...	...	...	...	45	...	60	110	120	210					

[a] Add auxiliary watts for total.

[b] Under burning hours per start listed.

[c] Lumen ratings apply at end of 100 hr. of use.

89. Slimline Lamps

All slimline lamps have a single-pin base—for instant-start hot-cathode operation

Nominal length and bulb diameter	42 in., T-6		64 in., T-6		72 in., T-8		96 in., T-8	
Maximum lamp length, in.	40		62		70		94	
Diameter, in.	¾		¾		1		1	
Minimum starting voltage	450		600		600		750	
Lamp watts (add auxiliary watts for total)	16	25	24	39	22	38	29	51
Lamp current, milliamp	100	200	100	200	100	200	100	200
Approx. lamp volts	180	150	285	230	250	220	335	295
Lumen output—white	930	1,400	1,440	2,250	1,410	2,350	1,890	3,200
Foot-lamberts—white	1,700	2,600	1,700	2,600	1,050	1,750	1,050	1,750

90. Circline Lamps

Four-prong, connector-type base

Lamp watts	32
Outside diameter of circle, in.	12 ± ¼
Diameter of tube	T-10(1¼″)
Lamp amperes (operating)	0.43
Lamp volts (operating)	84
Light output (white), lumens	1,600
Brightness, foot-lamberts	2,040

91. The advantages of the fluorescent lamp over the incandescent lamp are:

1. The lumen-per-watt efficiency is considerably greater than that for incandescent lamps, especially in the green and blue colors. This permits much higher levels of illumination for the same or less expenditure for power.

2. For the same amount of light the power consumption in watts and therefore the heat generated by the white and the daylight types is only about one-third that for incandescent lamps. For air-conditioned interiors this low heat dissipation affords considerable saving in installation and operating costs for the air-conditioning equipment.

3. The lamps operate at a temperature of only 100 to 120°F. and are therefore comparatively cool to the touch. The low heat radiation is an advantage in lighting display cases, especially where they contain perishable goods such as candy, flowers, fruits, and vegetables.

4. The colors are rich and vivid and permit of wide variety in decorative effects.

5. The color of the daylight lamp very closely approximates actual daylight, the principal deficiency being in the dark-red end of the spectrum

(Fig. 37), where the luminosity of the eye is low anyway. The daylight lamp is therefore very useful in illuminating fabrics, clothing, flowers, etc., to bring out their true colors. Where red objects are displayed or where people are trying on clothing, a red or pink lamp should be combined with the daylight lamps to compensate for the deficiency of the daylight lamp in the red end of the spectrum.

6. The long tubular shape lends itself well for use in concealed troughs, coves, niches, and counters.

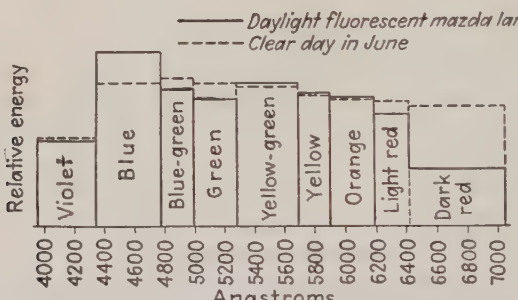


FIG. 37.—Spectral-energy distribution for the daylight fluorescent lamp compared with natural daylight. (*General Electric Co.*)

92. The disadvantages of the fluorescent lamps are:

1. The initial cost for fixtures and lamps is high. For lighting large areas the relatively low wattage per lamp requires that a very large number of lamps be installed

2. There is a time delay when the lamp is turned on, and it may be necessary to wait for the switch to cool down, when the lamp is turned off, before it can be turned on again.

3. The noise or hum produced in the reactor may be disturbing in very quiet locations.

4. There is a reduction in light output twice each cycle when the current wave passes through zero. This produces a flicker and may cause a dangerous stroboscopic effect when lighting moving machinery. This may be alleviated by combining two or three lamps in a fixture and wiring them on different phases of a two-or three-phase system. There is also available a tulamp auxiliary which puts a capacitor in series with one of the lamps so that its current will be out of phase with the other one. The current waves will then go through the zero point at different times.

5. The power factor of the cheaper auxiliary—the ordinary reactor type—is low, about 0.5. This may be avoided by using a capacitor type of auxiliary.

93. Auxiliary Equipment.—The operation of fluorescent lamps requires certain auxiliary equipment. Each fluorescent lamp requires a ballast

assembly, generally called simply a ballast. The characteristic of the mercury arc in the tube is that of a varying unstable resistance, which requires a high voltage to start the arc. Each lamp must therefore be equipped with a ballast reactor, which performs a twofold purpose. It provides a high induced starting voltage for striking the arc and, after conduction has started, stabilizes the operating impedance of the circuit in order to maintain the operating current at a steady value.

Since the ballast reactor used with the lamps gives an over-all lagging power factor of only 0.45 to 0.50, the installation of any considerable number of fluorescent lamps with simply a ballast reactor would require uneconomical size of wire and distribution transformer ratings in the circuits supplying the lamps. The power factor of the lamp circuit can be raised to a high value by connecting a capacitor of the proper rating across the lamp circuit. The use of power-factor-correcting capacitors is recommended. Many power companies have adopted rules, and several states have passed laws limiting the minimum power factor permissible in fluorescent-lamp installations. The power-factor correcting capacitor may be included as an integral part of the ballast assembly, or a large capacitor may be connected across the circuit supplying several lamps. A table of capacitance required per lamp for several sizes of lamps is given in Sec. **94B.**

All preheat-start lamps require an automatic starting switch. The available types of starting switches are explained in Sec. **95.**

In some preheat-start lamp circuits, an autotransformer is required. If the supply-line voltage is not within the rated limits of the lamp and ballast reactor, an autotransformer must be incorporated in the ballast assembly. Standard ballast assemblies are available so that lamps requiring 110 to 125 volts may be operated from 208- or 230-volt circuits.

Instant-start lamps do not require a starting switch but always do require an autotransformer for providing the high voltage necessary across the lamp for starting. The design of the ballast reactor and autotransformer must be so interrelated that the correct starting and operating voltages will be produced. They are therefore provided by the manufacturer as a unit in the ballast assembly.

94. Ballast Assemblies.—Certain parts of the auxiliary equipment required for fluorescent lamps are made up as a unit by the manufacturers and assembled inside a single metal case. The complete assembly is generally termed simply the ballast. Single-ballast assemblies are available for single-lamp, two-lamp (tulamp), three-lamp, and four-lamp (forlamp) luminaire installations. For preheat-start lamps, ballasts are available in the following combinations of auxiliary equipment: (1) only the ballast reactor (for use with a separate power-factor-correction capacitor for a group of lamps); (2) ballast reactor and power-factor-correction capacitor; and (3) ballast reactor, autotransformer, and power-factor-correction capacitor. The automatic starting

BALLAST
RED
BLACK
BLACK
RED
LAMP
A-C LINE
1
BALLAST
BLACK
WHITE
RED
LAMP
AC LINE
2
BALLAST
BLACK
WHITE
RED
SHUNT CAPACITOR
LAMP
AC LINE
3
BALLAST
BLACK
BLACK
LAMP
A-C LINE
4
BALLAST
BLACK
WHITE
CAPACITOR
RED
LAMP
AC LINE
5
BALLAST
BLACK
BLUE
BLUE
LAMP
LAMP
AC LINE
6
BALLAST
YELLOW
CONDENSATOR
RED
RED
BLUE CAPACITOR
BLACK
LAMP
LAMP
AC LINE
7
BALLAST
BLACK
WHITE
RED
LAMP
LAMP
A-C LINE
8
BALLAST
BLACK
WHITE
SHUNT CAPACITOR
RED
LAMP
AC LINE
9
BALLAST
YELLOW
BLACK
WHITE
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LAMP
LAMP
AC LINE
10
BALLAST
BLACK
WHITE
RED
LAMP
A-C LINE
11

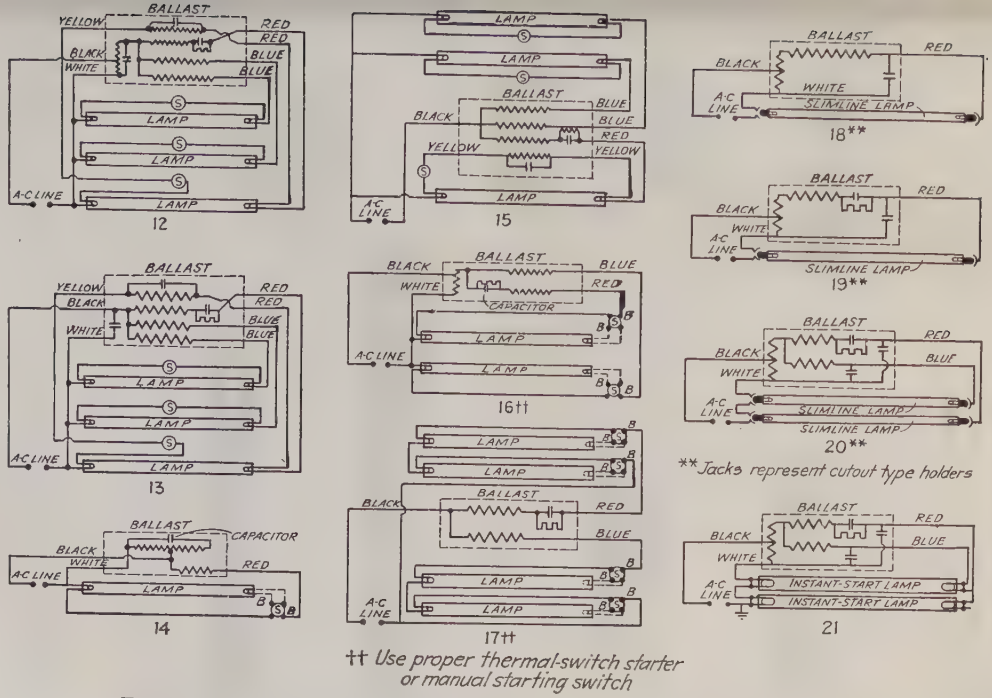


FIG. 38.—Circuits for fluorescent lamps and ballasts. (*General Electric Co.*)

switch required for the preheat-start lamps is not combined with the ballast assembly but is made as a separate unit. For instant-start lamps all the required auxiliary equipment is combined in the ballast assembly.

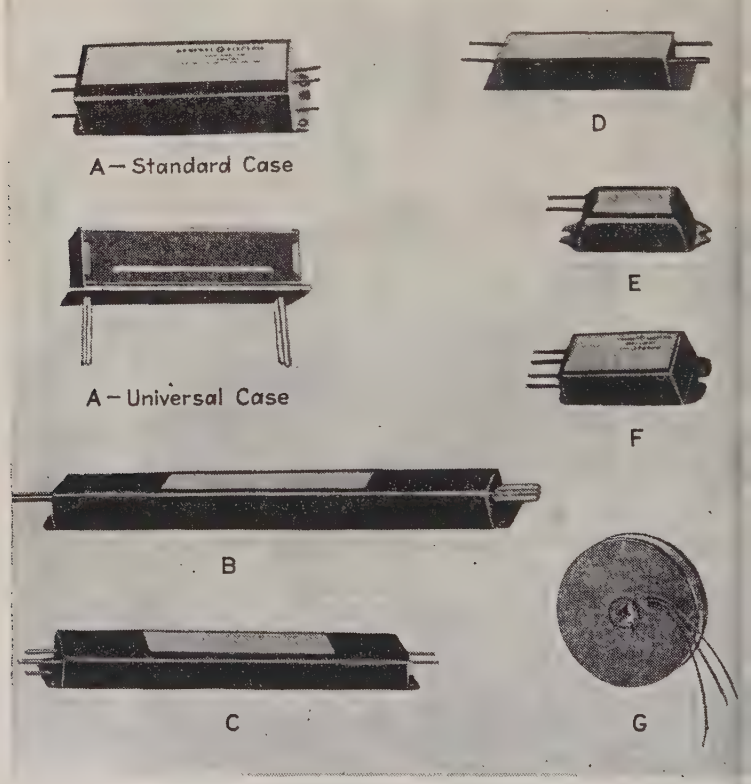


FIG. 38*A*.—Fluorescent-lamp ballasts.

A table of standard ballasts is given in Sec. **94A**, the corresponding wiring diagrams in Fig. 38, and the appearance of the cases in Fig. 38*A*.

94A. Table of 60-cycle Standard Ballasts (*General Electric Co.*)

Lamp watts		Circuit voltage	Standard package	Approx. size, in.	Approx. watts loss	Approx. power factor	Line current, amp.	Fig. No.[a]	Case type[b]
For Fluorescent Lamps with Miniature Bipin Bases									
6	6	110–125	20	1¼ × 1¾ × 4¼	2	45	0.16	1	F
8	8	110–125	20	1¼ × 1¾ × 4¼	2.8	45	0.175	1	F
13	13	110–125	10	1⅜ × 2¼ × 7½	7	45	0.37	2	C
	13	110–125	10	1⅜ × 2¼ × 9⁷⁄₁₆	6	95[c]	0.19	3	C
For Fluorescent Lamps with Medium Bipin Bases									
14	14	110–125	20	1¼ × 1¾ × 4¼	3.6	44	0.37	4	E
	14	110–125	10	1⅜ × 2¼ × 8¾	3.6	85[c]	0.18	5	C
	2–14	110–125	10	1¼ × 1¾ × 6½	7.2	44	0.74	6	E
15	15	110–125	20	1¼ × 1¾ × 4¼	4.5	55	0.30	4	E
	15	110–125	10	1⅜ × 2¼ × 8¾	4.5	90[c]	0.19	5	C
	2–15	110–125	10	1¼ × 1¾ × 6½	9	55	0.60	6	E
	2–15	110–125	10	1⅜ × 2¼ × 14¼	9	95[c]	0.35	7	C
20	20	110–125	20	1¼ × 1¾ × 4¼	4.5	55	0.35	4	E
	20	110–125	10	1⅜ × 2¼ × 8¾	4.5	90[c]	0.23	5	C
	2–20	110–125	10	1¼ × 1¾ × 6½	9	55	0.70	6	E
	2–20	110–125	10	1⅜ × 2¼ × 14¼	9	95[c]	0.45	7	C
30	30	199–216 220–250	10	1¼ × 1¾ × 6½	6 7	60 60	0.34 0.34	4 4	E E
	30	110–125	10	1⅜ × 2¼ × 14¼	9	90[c]	0.36	9	C
		199–216	10	1⅜ × 2¼ × 10⅝	6.5	90[c]	0.23	5	C
		220–250	10	1⅜ × 2¼ × 10⅝	7	90[c]	0.20	5	C
	30	110–125	10	1⅜ × 2¼ × 8¾	8.5	55	0.65	8	C
	2–30	110–125	10	2⅜ × 3⅛ × 9½	12.5	95[c]	0.7	10	A
		199–216	10		10.0	95[c]	0.4	10	A
		220–250	10		10.5	95[c]	0.35	10	A
	2–30	110–125	10	1⅜ × 2¼ × 18¼	16	95[c]	0.7	10	B
		199–216	10		10	95[c]	0.4	10	B
		220–250	10		12	95[c]	0.35	10	B
40	40	110–125	10	1⅜ × 2¼ × 8¾	9.5	60	0.85	8	C

Table of 60-cycle Standard Ballasts (*General Electric Co.*) (*Continued*)

Lamp watts		Circuit voltage	Standard package	Approx. size, in.	Approx. watts loss	Approx. power factor	Line current, amp.	Fig. No.[a]	Case type[b]
For Lamps with Meduim Bipin Bases (*Continued*)									
40	40	199–216	10	1¼ × 1¾ × 6½	10	60	0.41	4	E
		220–250	10		10.5	60	0.41	4	E
	40	110–125	10	1⅜ × 2¼ × 14¼	9.5	95[c]	0.50	9	C
		199–216	10	1⅜ × 2¼ × 10⅝	8.5	95[c]	0.29	5	C
		220–250	10	1⅜ × 2¼ × 10⅝	9.5	95[c]	0.26	5	C
	40	240–280[d]	10	2⅜ × 3⅛ × 9½	10	90[c]	0.22	11	A
	2–40	110–125	10	2⅜ × 3⅛ × 9½	15.5	95[c]	0.85	10	A
		199–216	10		11.5	95[c]	0.5	7	A
		220–250	10		12.5	95[c]	0.43	10	A
		240–280[d]	10		15.0	95[c]	0.4	10	A
	2–40	110–125	10	1⅜ × 2¼ × 18¼	19	95[c]	0.85	7	B
		199–216	10		13	95[c]	0.5	7	B
		220–250	10		15	95[c]	0.43	7	B
	3–40	110–125	4	2⅜ × 3⅛ × 14⅜	23	95[c]	1.3	12	A
		199–216	4		16	95[c]	0.7	13	A
		220–250	4		20	95[c]	0.6	13	A
		240–280[d]	4		20	95[c]	0.6	12	A
	3–40	199–216	10	2⅜ × 3⅛ × 9½	14	90[c]	0.7	15	A
	3–40	220–250	10	2⅝ × 3⅛ × 9½	15.5	85[c]	0.64	15	A
For Fluorescent Lamps with Mogul Bipin Bases									
100	100	110–125	4	2⅜ × 3⅛ × 14⅜	24	90[c]	1.22	14	A
		199–216	4		30	90[c]	0.75	14	A
		220–250	4		30	90[c]	0.65	14	A
		240–280[d]	4		30	90[c]	0.5	14	A
	2–100	110–125	4	2⅜ × 3⅛ × 19¼	32	95[c]	2.1	16	A
		199–216	4		32	95[c]	1.25	16	A
		220–250	4		32	95[c]	1.1	16	A
		240–280[d]	4		35	95[c]	1.0	16	A
	4–100	250–280[d]	4	2⅝ × 3⅛ × 19¼	36	95[c]	1.65	17	A
For Circline Fluorescent Lamp with 4-Prong Base									
32	32	110–125	10	1⅜ × 6	11	50	0.67	2	G
	32	110–125	10	1⅜ × 8	9	90[c]	0.38	3	G
	2–32	110–125	10	1⅜ × 8	16	95[c]	0.73	10	G
	....	.....	50	5⅛ × 5¾	..	..	.....	..	G

Table of 60-cycle Standard Ballasts (*General Electric Co.*) (*Continued*)

Lamp size	Lamp watts	Standard package	Approx. size, in.	Approx. watts loss	Approx. power factor	Line current, amp.	Fig. No.[a]
For Fluorescent Lamps with Single-pin Bases (Slimline)[f] No Starters required. Type A Universal Case							
42T6	16	10	2⅜ × 3⅛ × 9½	11	45	0.50	18
	16	10	2⅜ × 3⅛ × 9½	10	95[c]	0.35	19
	2–16	10	2⅜ × 3⅛ × 9½	11.5	95[c]	0.40	20
	25	10	2⅜ × 3⅛ × 9½	15.5	32	0.90	18
	25	4	2⅜ × 3⅛ × 11¾	17	95[c]	0.56	19
	2–25	4	2⅜ × 3⅛ × 11¾	18	95[c]	0.65	20
64T6	24	10	2⅜ × 3⅛ × 9½	12.5	45	0.70	18
	24	10	2⅜ × 3⅛ × 9½	10	95[c]	0.35	19
	2–24	4	2⅜ × 3⅛ × 11¾	15	95[c]	0.60	20
	39	10	2⅜ × 3⅛ × 9½	22	40	1.40	18
	39	4	2⅜ × 3⅛ × 11¾	17	95[c]	0.56	19
	2–39	4	2⅜ × 3⅛ × 14¼	24	95[c]	1.0	20
72T8	22	10	2⅜ × 3⅛ × 9½	12.5	45	0.70	18
	22	10	2⅜ × 3⅛ × 9½	10	95[c]	0.35	19
	2–22	4	2⅜ × 3⅛ × 11¾	15	95[c]	0.60	20
	38	10	2⅜ × 3⅛ × 9½	22	40	1.40	18
	38	4	2⅜ × 3⅛ × 11¾	17	95[c]	0.56	19
	2–38	4	2⅜ × 3⅛ × 14¼	24	95[c]	1.0	20
96T8	29	10	2⅜ × 3⅛ × 9½	11.5	95[c]	0.41	19
	2–29	4	2⅜ × 3⅛ × 11¾	16	95[c]	0.72	20
	51	4	2⅜ × 3⅛ × 14¼	19.5	95[c]	0.67	19
	2–51	4	2⅜ × 3⅛ × 19¼	28	95[c]	1.30	20
Tulamp Ballast for 40-watt Instant-starting Medium or Mogul Bipin Base Lamp							
[f]	2–40	4	2⅜ × 3⅛ × 14⅜	28	95[c]	0.98	21

[a] See Fig. 38.
[b] See Fig. 38A.
[c] High-power-factor ballasts are recommended. Where other ballasts are used, the power-factor-correction capacitors listed in Sec. **94C** are recommended.
[d] For Y-connected networks rated 254/440, 265/460, and 277/480 volts. Ballasts are connected line to neutral. In no case use less than 250 volts.
[e] Note that some ballasts may be used for two or more lamp sizes.
[f] For either 48-in. T-12 or 60-in. T-17 40-watt lamp.

94B. Table of Capacitors for Power-factor Correction (*General Electric Co.*)

Lamp size	Circuit volts	Mfd. needed per lamp for 90 per cent p.f.	Class capacitors that will correct the indicated number of lamps to 87 per cent power factor or better. Data for 60 cycles				
			1	2	3	4	5
15-watt, T- 8	118	4.2	M	N	N	P	MP
15-watt, T-12	118	5.2	M	N	P	MP	NP
20-watt, T-12	118	4.7	M	N	P	P	MP
30-watt, T- 8	118	8.5	N	P	NP	PP	NPP
30-watt, T- 8	208	2.6	M	M	N	N	N
40-watt, T-12	118	8.7	N	P	NP	PP	NPP
40-watt, T-12	236	2.6	M	M	N	N	N

Key	Mfd.	Length, in.
M	4.75	8¾
N	12	14¼
P	18	17½

More than one letter means the capacitors are to be connected in parallel, across the line.

95. The starting switches required for preheat-start lamps must perform at least the following functions:

1. Close the circuit between the two filaments when the lamp circuit is energized.

2. Open the circuit between the two filaments after a sufficient lapse of time for the filaments to be heated to the proper temperature.

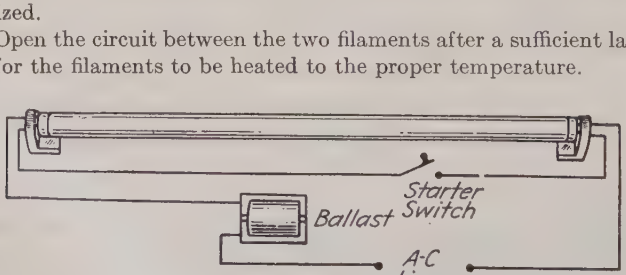


FIG. 39.—Fluorescent-lamp circuit with push-button starting switch.

Starting switches are available in four types: (1) manual starting switches, (2) automatic glow-switch starter, (3) automatic Watch-Dog or No-Blink starters, and (4) automatic thermal-switch starters.

The manual starting switch is the simplest concept of a starter switch. It consists of a single push-button type of switch, as indicated in Fig. 39. In starting the lamp, the push button is held down for a second or two and then released. Manual starting switches of this type are often used for desk-type fluorescent lamps.

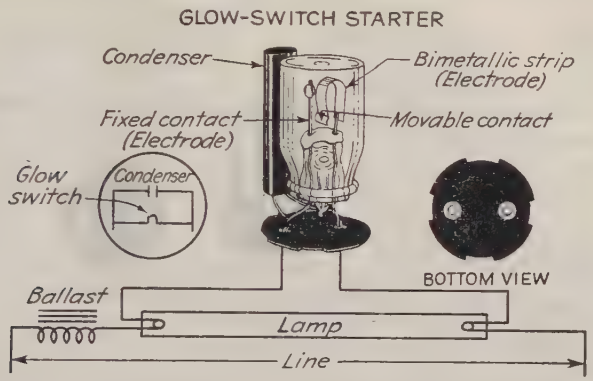


FIG. 39A.—Fluorescent-lamp circuit with glow-switch starter.

The automatic **glow-switch starter** (Fig. 39*A*) consists of a glass bulb containing neon or argon gas and two electrodes. One electrode is a U-shaped bimetallic strip, and the other electrode is a fixed rod. On starting, when there is practically no voltage drop at the ballast, the voltage at the starter is sufficient to produce a glow discharge between the U-shaped bimetallic strip and the fixed-contact or center electrode (see Fig. 39*B-a*. The heat from the glow actuates the bimetallic strip, the contacts close, and cathode preheating begins (see Fig. 39*B-b*). This shorts out the glow discharge so the bimetal cools, and in a very short time the contacts open (see Fig. 39*B-c*). The inductive voltage kick from the ballast is then sufficient to start the lamp. During normal operation, there is not enough voltage across the lamp to produce further starter glow; the contacts therefore remain open, and the starter consumes no energy.

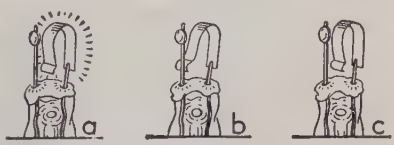


FIG. 39B.—Glow-switch starter, showing operating positions of contacts.

The Watch-Dog starter (one manufacturer's trade name), (Fig. 39*C*) contains a glow switch; and, during normal starting, the switch functions in the manner described. This starter has an added feature, which consists of a wire-coil heater element actuating a bimetallic arm that serves as a latch to hold a second switch in a normal closed position. When a lamp is deactivated or will not start for some reason after making repeated

attempts by blinking on and off, enough heat is developed by the intermittent flow of cathode-preheating current so that the latch pulls away and releases a spring-operated switch in the starter circuit. This occurs after 15 to 20 sec. at rated line voltage, thus removing the annoyance of blinking and conserving the life of the starter. At the time the lamp is

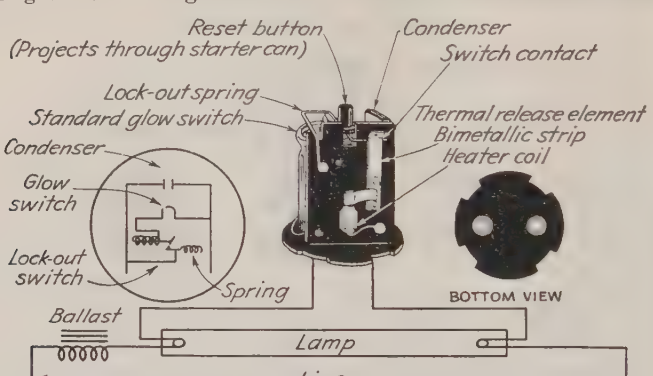


FIG. 39C.—Fluorescent-lamp circuit with Watch-Dog starter.

replaced, the starter is reset to operating position by pushing down on the reset button at the top of the starter. The No-Blink starter is another manufacturer's trade name for a starter that performs the same function as the Watch-Dog starter. Its operation is similar to that of the Watch-Dog starter.

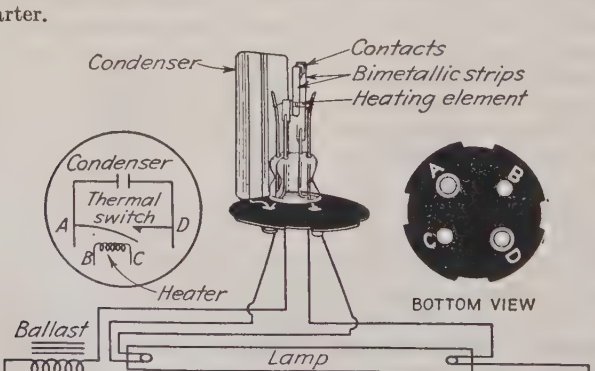


FIG. 39D.—Circuit for fluorescent lamp with thermal-switch starter.

The thermal-switch starter consists of a bimetallic switch element heated by a separate heater element. The arrangement and connections

for such a starter are shown in Fig. 39*D*. When cold the bimetallic switch element is closed. When the lamp circuit is energized, the bimetallic switch element connects the ballast, starter heating element, and lamp cathodes in series across the supply line. The cathode-preheating current, in passing through the starter heating element, heats the bimetallic switch element. After the proper lapse of time, the heating of the bimetallic switch element opens the contacts of the bimetallic switch element and breaks the circuit through the lamp filaments. The inductive kick then starts the lamp. The normal operating current passes through the starter heating element. The bimetallic switch element is therefore held open as long as the lamp continues to conduct. The thermal-switch starter consumes some energy during operation, ½ watt for the smaller size and 1½ watts for the larger size. The thermal-switch starters probably give the best all-around performance. They provide an adequate preheating period, a high induced starting voltage, and characteristics that are inherently less susceptible to line-voltage variations.

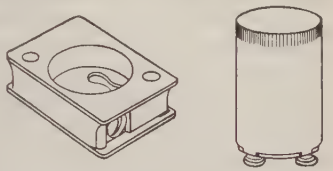


FIG. 39*E*.—Fluorescent-lamp starter switch and socket.

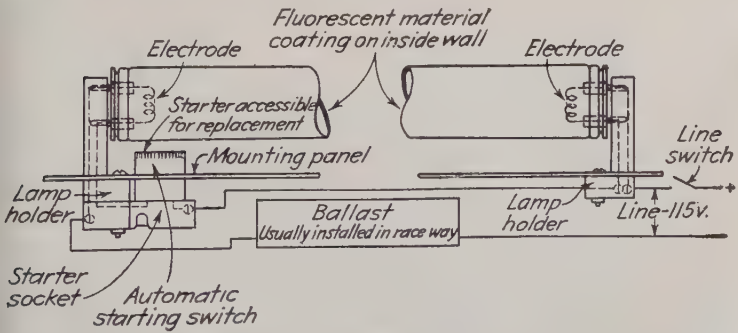


FIG. 39*F*.—Assembly of fluorescent lamp, starter, and reactor.

A small capacitor is connected across the switch contacts in all the types of automatic starting switches. It aids in the starting but is primarily useful to shunt out line-lead harmonics that may cause radio interference.

The general appearance of automatic starting switches is shown in Fig. 39*E*.

Automatic starting switches are mounted in special starter sockets that are available as a separate unit or as a unit combined with a fluorescent lamp holder.

95A. Wiring Arrangement.—A typical wiring arrangement for a fluorescent lamp and its auxiliaries is shown in Fig. 39*F*.

95B. Ballast Operating Temperatures.—The conventional ballast is enclosed in a container filled with a heavy impregnating compound which congeals around the choke coils and condenser. This serves to radiate heat and, by its compactness, to eliminate or minimize noise or hum. The wattage loss in the ballast creates heat, and suitable ventilation must be provided in fixture design or in places where ballasts are installed so that the temperature is kept within safe limits. If the temperature rises too high, the capacitor will fail and cause excessive heating and eventual failure of the transformer winding. Excessive temperature may also result from overvoltage operation.

The temperature of a ballast measured on the case should not exceed 194°F. with continuous operation and with the starter switch short-circuited; this condition may occur in practice and represents the condition of maximum wattage absorption by the ballast. Capacitors are more susceptible to damage by high temperature, and the safe limits depend on the type; however, in no case should the operating temperature exceed 167°F. for any type of capacitor.

96. D-c Operation.—If fluorescent lamps are used on d-c circuits special auxiliaries and proper series resistance must be employed. However, d-c operation is inferior to that of normal a-c operation in several respects: (1) the over-all efficiency of light production is much less on d-c circuits because the series resistance consumes about as much wattage as the lamp itself; (2) rated average life is only 80 per cent of the a-c value; (3) suitable line reversing switches to change polarity with each lamp start should be provided for 30-, 40-, and 100-watt lamps; and (4) lumen maintenance may be somewhat less favorable. On the other hand, the color of the light and the total light output compare favorably with normal a-c operation, and problems of power factor and stroboscopic effect are, of course, eliminated.

97. Radio Interference.—The performance of the mercury arc of a fluorescent lamp at the electrodes is associated with an electrical instability that sets up a continuous series of radio waves. There are three ways in which these waves may reach the radio and interfere with reception:

1. Direct radiation from the bulb to the radio aerial circuit.
2. Direct radiation from the electric supply line to the aerial circuit.
3. Line feedback from the lamp through the power line to the radio.

The direct radiation from the bulb diminishes rapidly as the radio is separated from a lamp, and this effect can be controlled by proper positioning of the radio and its aerial. The table shows the extent and comparative amount of bulb radiation for various sizes of fluorescent lamps. It will be seen that, if the aerial is at least 9 ft. from the lamp, interference by bulb radiation is negligible.

Extent of Bulb Radiation
(Values are Relative)

Lamp	Aerial 2 ft. from lamp	Aerial 4 ft. from lamp	Aerial 6 ft. from lamp	Aerial 8 ft. from lamp	Aerial 10 ft. from lamp
40- or 100-watt	100	47	9	4	0
30-watt	90	43	8	1	0
20-watt	75	35	7	0	0
15-watt	55	26	5	0	0

If the radio must remain within the bulb-radiation range, it will be necessary to take the following precautions:

1. Connect the aerial to the radio by means of a shielded lead-in wire with the shield grounded, or install a "doublet" type of aerial with twisted pair leads.
2. Provide a good ground for the radio.
3. Aerial proper must be out of bulb- and line-radiation range. The use of a correct antenna system will usually help reduce radio interference by providing a better station signal strength.

Interference from line radiation and line feedback can best be minimized by the proper application of line filters at each lamp or fixture. A simple form of filter is a three-section capacitor unit. One such unit per fixture (or for each 8 ft. of lamps in a cove) will reduce line noise approximately 75 per cent. Where it is desirable to eliminate line noise completely, the inductive-capacitor type is recommended. This filter has a current-carrying capacity of 2 amp., which is, for example, about the load of four 40-watt lamps.

Where only one or two radios are located near a fluorescent installation and the aerial circuit has been properly shielded from bulb and line radiation, a single line filter located at the radio power outlet will suffice.

Where radios located in buildings adjoining the fluorescent installation are receiving line feedback type of interference, it is practical to install a single filter such as the three-section capacitor unit at each panel box feeding fluorescent lamp circuits.

Where it is necessary to filter each lamp or fixture, the filter should be located as close to the lamps as possible. This precaution should be taken because of line radiation between lamp and filter.

Lamp holders improperly spaced resulting in poor contact with lamp base pins can also generate interference, as can fluorescent fixtures improperly grounded. Failure to ground the neutral of branch circuits (as required in the National Electric Code) is an additional cause. If the service lines are not properly grounded, filters will be much less effective.

Fluorescent equipments destined for home or other use where radios ar likely to be present should have the proper radio-interference filter in eac fixture.

98. Average Life.—Published values of fluorescent lamp life ar determined by life testing a selection of lamps each month from eac factory. Precise test procedures are followed. Circuit voltages ar closely regulated, the starters used deliver proper preheat, and the ballast are accurately rated for the designed lamp voltage and current. Unde these specified test conditions, average life and the mortality rate can b determined, though it will be noted that some lamps fail before rated lif is realized, whereas others may live considerably longer than averag life.

In actual installations, the life obtained may be more or less than pub lished values, depending on the departure from standard test condition Where lamps are turned on and off frequently or where the lamps blin several times before starting, generally because of a poor starter or lo voltage, the life will be shortened; in installations that burn continuously as in many industries, a life of 10,000 hr. or more may be experienced although the depreciation may be so severe that most economical opera tion is not obtained.

Life Ratings of Fluorescent Lamps

Lamp	Burning hr. per start	Rated average life, hr.
6- and 8-watt, T-5	3	1,500
13-watt, T-8	3	1,500
14-watt T-12	3	2,000
15-watt, T-8	3	2,500
30-watt, T-8	6	4,000
	12	6,000
15-watt, T-12	3	2,500
20-watt, T-12	6	4,000
40-watt, T-12	12	6,000
All Slimline lamps		
40-watt, T-12 48-in. (instant start)	3	2,500
40-watt, T-17 60-in. (low brightness)		
100-watt, T-17	3	3,000
	6	4,500
	12	6,500

99. The temperature of the bulb has a decided effect on the efficiency of the fluorescent lamp (Fig. 40). The best efficiency occurs at 100 to 120°F., which is the operating temperature corresponding to an ambient

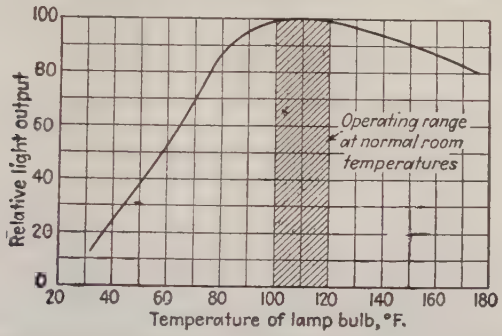


FIG. 40.—Effect of bulb wall temperature on the efficiency of the fluorescent lamp.

room temperature of 70 to 80°F. The efficiency decreases slowly as the temperature is increased above normal but decreases very rapidly as the temperature is decreased below normal. For this reason the fluorescent lamp is not satisfactory for locations where it will be subject to wide variations in temperature. This reduction in efficiency with low surrounding air temperature may be minimized by enclosing the lamp within a clear glass tube so that the lamp will operate at more nearly its desirable temperature (Fig. 41).

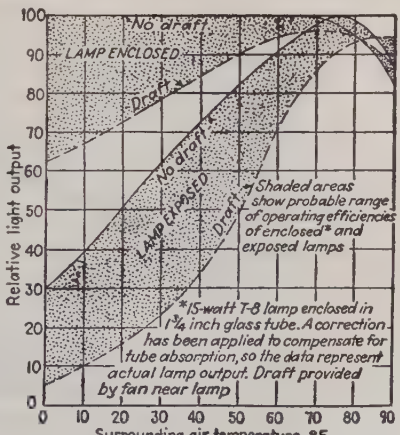


FIG. 41.—Effect of surrounding air temperature on the efficiency of the fluorescent lamp.

100. Variations in line voltage produce less effect on fluorescent lamps than on incandescent lamps, the phase relationship between line voltage, lamp voltage, and auxiliary voltage being such that the lamp voltage varies inversely as the square root of the line voltage (Fig. 42). For this reason, fluorescent lamps are rated for a nominal circuit voltage of 110 to 125, and the auxiliary is designed for 118 volts, instead of 110, 115, or 120 volts as in the case of incandescent lamps. Line voltage less than 110

may make the starting of the arc uncertain; over 125 volts may overhea the auxiliary. Line voltages less than 110 or greater than 125 wil decrease the life of the lamp. Although auxiliaries are available fo operating the lamps on 220- to 250-volt and 199- to 216-volt systems there is no advantage in using these voltages, and it is expected that 110 to 125-volt operation will become practically standard.

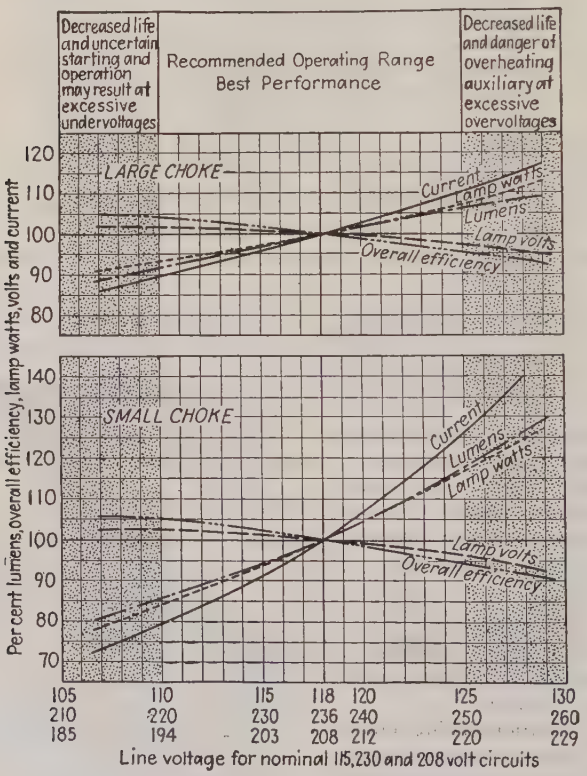


FIG. 42.—Effect of variation of line voltage on the operating characteristic of fluorescent lamps.

101. Operating Suggestions (General Electric Co.).—To secure the bes performance of fluorescent lamps, it is important that the user under stand how to maintain his fluorescent installation properly. Man factors that affect the performance of these lamps were never encountere with incandescent filament lamps, and the user must realize that some o these new elements of satisfactory service are within his control.

For example, if a filament lamp does not light when current is applied, the one single, positive conclusion is that the lamp is burned out or defective. No such conclusion should be made in the case of the fluorescent lamp. This lamp, though perfect in all respects, may not start or operate properly through no fault of its design or manufacture. Specifications based on the attainment of best lamp performance govern the design and construction of auxiliary equipments. Because of these requirements, satisfactory lamp performance can be assured only when they are used with auxiliary equipments which meet the MAZDA Lamp Manufacturers' Specifications for MAZDA F Lamp Auxiliaries. All ballasts and starters certified by the Electrical Testing Laboratories comply with these specifications.

Average Life.—Since mortality laws apply to fluorescent as well as to filament lamps, it is not unusual for some fluorescent lamps to fail after a few hundred hours while others will last longer than their rated average life to balance out the normal early failures.

Normal Failure.—The electroemissive material on fluorescent-lamp electrodes is used up during the life of the lamp, the "sputtering off" being more rapid during starting. Therefore, a longer life will be obtained if lamps are allowed to operate continuously instead of being burned on and off frequently. Rated life should be obtained on the average if lamps are operated for normal periods of 3 or 4 hr.

When the active material on the electrodes is used up, the lamp will simply blink on and off, sometimes with a shimmering effect during the period that the lamp remains lighted. Most fluorescent lamps fail in this manner.

Normal Depreciation.—The light output at 100 hr. is used for rating purposes, because the loss during this period may amount to as much as 10 per cent. The average light output during life is approximately 90 per cent of the 100-hr. rating value.

Blackening.—Fluorescent lamps blacken rather uniformly throughout the length of the tube during life, though this is not noticed unless an old lamp is compared with a new one in front of a light source. At the end of life, the lamps usually show a dense blackening at either one end or both. Also, there may be dark rings, slightly brownish in color, at one end or both. On the average, there should be little indication of either blackening or rings during the first 500 hr. of operation.

Circuit Voltage.—The circuit voltage should be within the ballast rating, although 110- to 125-volt ballasts *may in some cases* give satisfactory lamp performance on circuits as low as 105 or as high as 130 volts. Ballasts designed for 220 to 250 volts *may sometimes* give satisfactory results on line voltages as low as 210 and as high as 260 volts. Excessive under- or overvoltage is injurious to the lamp.

Transformer Hum.—Characteristic "transformer hum" is inherent in lamp ballast equipment, although the noise may "come and go," varying

considerably with individual ballasts. By mounting ballasts on so rubber, Celotex, or similar nonrigid mountings, the vibrations due to th magnetic action in the chokes will not be transferred to supportin members, and disconcerting auxiliary hum will be reduced to a minimun Such vibration insulation, however, should not inhibit heat radiation an transfer to such a point that ballast ambient temperature limits ar exceeded.

Low-temperature Operation.—In most cases, satisfactory starting an performance can be expected at temperatures considerably below 50°F by (1) keeping the voltage in the upper half of the ballast rating, (2 conserving lamp heat by enclosure or by some other suitable means, an (3) using thermal starting switches.

Starting Difficulty.—Starting difficulties may be due to a number o causes other than the starter itself. In general, any difficulty in startin may result in premature end blackening and short lamp life.

If a Lamp Makes No Effort to Start.—First the lamp should be checke to make sure that it is properly seated in the sockets. If so, the starte should be checked; it may have reached the end of life and should b replaced. If this fails to correct the trouble, the lamp should be checke in another circuit; and, if necessary, the voltage may be checked at th sockets. If no indication of power is found at the sockets, the circu connection are incorrect or the ballast is defective.

If a Lamp Is Slow in Starting.—A sluggish starter is usually the cause o such trouble, and the starter should be replaced. Low line voltage, lo ballast rating, and omission of starting compensator in the leading circu of two-lamp ballasts can also result in slow starting.

If the Ends of a Lamp Remain Lighted.—This indicates a short circuit i the starter, and it should be replaced. Starters that have been in servic for some time frequently fail in this manner. If the ends of a lamp in new installation remain lighted, it is possible that the wiring is incorrec Of course, where short-circuiting types of No-Blink or Watch-Dog starte are used, the lamp ends will remain lighted in a normally failed lamp this automatically corrects itself when the lamp is replaced.

If a Lamp Blinks On and Off.—This is the usual indication of a norm failure of a lamp. It will usually be found more convenient to put in new starter first and then, if blinking continues, renew the lamp. Lo circuit voltage, low ballast rating, low temperature, and cold draf may individually cause difficulties of this nature, or several may b contributing factors. It is also possible for improper circuit connectio to cause such blinking. The annoyance of blinking lamps can b avoided by using No-Blink starters, in installations employing lamps fo which such types of starters are available.

CAUTION.—If the ends of a lamp remain lighted or the lamp blinks o and off, the trouble should immediately be corrected or the lamp c

starter removed from the circuit. A blinking lamp can shortly ruin both lamp and starter. Ordinary starters can be replaced with No-Blink starters (where available) which remove the starter element from the circuit if lamps fail to light after a reasonable number of attempts.

Early end blackening indicates improper operating conditions. Heavy end blackening early in life indicates that the active material on the electrodes is being sputtered off too rapidly. It may be due to:

1. High or low voltage. For best results, the circuit voltage should be within ballast rating.

2. Loose Contacts (most likely at lamp holder) causing lamp to blink on and off. Remedy: Lamp holders should be rigidly mounted and properly spaced. See that lamps are securely seated in lamp holders.

3. Improperly designed ballasts or ballast outside specification limits. Remedy: The use of ballasts approved by the Electrical Testing Laboratories will usually eliminate trouble of this nature.

4. Defective or worn-out starter, causing lamp to blink "on" and "off," or prolonged flashing of the lamp at each start, or ends of the lamp to remain lighted over a period of time. Remedy: Replace with new starter.

5. Omission of starting compensator in leading circuit of a two-lamp ballast. Remedy: Install a compensator.

6. Improper wiring of units.

GASEOUS-DISCHARGE LAMPS—GENERAL

102. Light is produced by gaseous-conduction methods (General Electric Co.) when proper energy transitions result from electron displacement within the atomic structure of the gas involved. Applied voltage at the electrodes gives acceleration to free electrons which, in the course of their travel, strike atoms and displace electrons from their normal atomic positions. Radiations of a particular wave length result as the displaced electrons return to their normal position in the atomic structure; this wave length depends on the gas used and the degree of electron displacement.

Once the discharge begins, the enclosed arc becomes a light source with one electrode acting as a cathode and the other as an anode. The electrodes will exchange functions as the supply changes polarity. This principle is employed in mercury-vapor, sodium-vapor, and neon lamps.

MERCURY-VAPOR LAMPS FOR GENERAL ILLUMINATION

103. Mercury-vapor lamps (visible-light type) are of two types:

1. Cooper-Hewitt.
2. Mazda H.
   a. H-1. *c.* H-6.
   b. H-2. *d.* H-9.

The essential difference between the Cooper-Hewitt and the Mazd H lamps is in the gaseous pressure at which they operate, the Cooper Hewitt being a low-pressure lamp and the Mazda H a high-pressure on

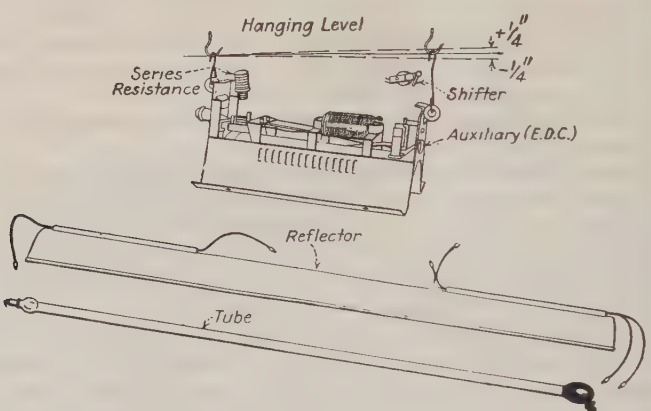


FIG. 43.—Parts of Cooper-Hewitt lamp.

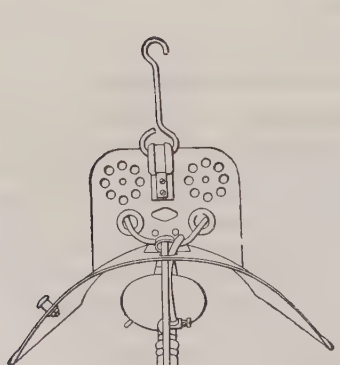


FIG. 44.—Cathode (negative) connections of Cooper-Hewitt lamp, showing reflector in normal position.

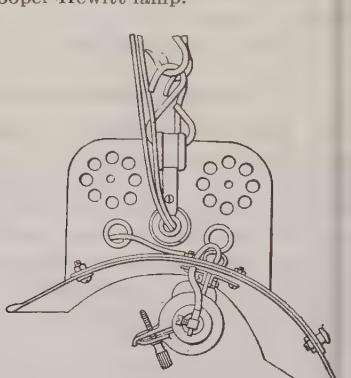


FIG. 45.—Anode (positive) connection of Cooper-Hewitt lamp, showing reflector rotated 20 deg.

104. The quality of light from a mercury-vapor lamp is peculiar. contains no red rays and has a peculiar bluish-green color, which great distorts the color values of objects viewed by it. For work in which is not necessary to distinguish color values, two advantages are claim by the maker: (1) Owing to the absence of red rays, it is easy on the ey

since these rays are the least effective in producing vision and, owing to their heating power, are irritating and fatiguing to the retina. (2) The approximately monochromatic nature of the light promotes acuity of vision, *i.e.*, objects are seen more sharply and details are more easily discernible than by white light. The lamps are chiefly useful for drafting, photography, and for lighting large manufacturing areas. For certain services, tin-plate inspection for example, there is no other light which will disclose imperfections which the mercury-vapor light reveals readily.

105. The Cooper-Hewitt mercury-vapor lamp consists of three essential parts: the tube or light-giving part, the reflector, and the operating mechanism.

The tube (Fig. 43) is of clear glass 1 in. in diameter and 50 in. long, with electrodes at each end and containing a small quantity of metallic

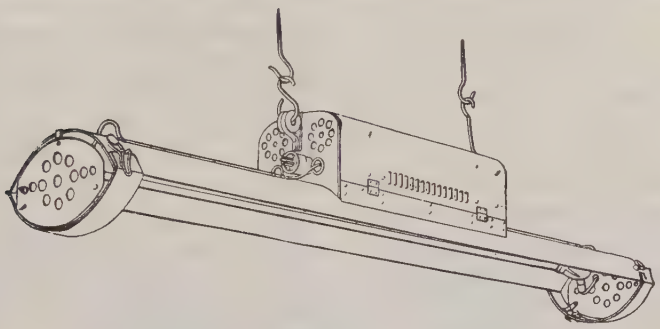


Fig. 46.—Assembled Cooper-Hewitt lamp.

mercury. The air is exhausted and the tube then sealed. The mercury is held in the large bulb at one end of the tube, and serves as the negative electrode, the tube being always so suspended that this bulb is the lowest part of the tube. The positive electrode is a small iron cup at the other end of the tube. The current is conveyed to the electrodes through platinum wires sealed in the glass. The current, passing from the positive electrode to the negative, vaporizes some of the mercury and causes the vapor to become luminous.

The tube is mounted in a metal reflector, coated on the underside with white enamel. The reflector (Fig. 43) extends over the full length of the tube and down the sides to a point 18 deg. below the center line of the tube. The mercury-vapor lamp produces direct illumination. The reflector may be adjusted for three different positions. The standard position (Fig. 44) is with the reflector directly over the tube with its sides extending down the same amount on each side below the center line of the tube. The reflector may be rotated 20 deg. either to the left or to the right (Fig. 45). This rotation of the reflector does not change the

shape of the light-distribution curve but simply rotates the complete curve 20 deg. to the left or right about the light center. This feature is useful in cases where illumination on vertical surfaces is of great importance.

The operating mechanism consists of the stabilizing coils and the mercury starting switch or shifter. An assembled mercury-vapor lamp is shown in Fig. 46.

Cooper-Hewitt lamps may be obtained for operation on direct current or alternating current. The principal characteristics are given in Table 106, and the dimensions are shown in Figs. 47 and 48.

106. Specifications—Cooper-Hewitt Industrial Lighting Units

Characteristic	Alternating current		Direct current
Code No., standard unit	160-H9WL1	260-H9WL1	110-H9WL1
Voltage range	Connections for 95-100-111 / 103-110-121 / 112-120-130	Connections for 190-200-222 / 206-220-242 / 224-240-260	100-110-125[a]
Total average watts per lamp	450	450	385
Average line amp	4.65	2.3	3.5
Power factor, per cent	88	88	
Candle power, mean hemispherical with curved reflector	900	900	800
Rated total lumens, lower hemisphere	5,600	5,600	5,200
Lumens per watt, lower hemisphere	12.5	12.5	13.4
Light source, diam. 1 in	50 in. long	50 in. long	50 in. long
Frequency	60-50 cycle	60-50 cycle	
Special units available for	25-40 cycle	25-40 cycle	

[a] Automatic regulation.

107. Operation of D-c, Mercury-vapor Lamps.—The wiring diagram of a d-c, mercury-vapor lamp is shown in Fig. 49. The main circuit of the lamp (Fig. 49) is from the positive side of the line to 1 and 2, through the tube to 3, to 4, through the shifter inductance coils to 5, through the stabilizing resistance, and back to the negative side of the line. The mercury starting switch or shifter in series with the starting resistance is connected in parallel with the tube across the line. When the line switch is open, the mercury starting switch is in such a position that the mercury in its tube forms a closed circuit between the two terminals of the switch. When the line switch is closed, no current will flow at first through the tube of the lamp since the mercury is cold, and there is no mercury vapor in the tube to start the arc. Upon closing of the line switch there is, however, a closed circuit from the positive side of the line to 1 and 6, through the starting resistance to 7, through the starting switch to 4, through the shifter inductance coils to 5, through the series

resistance to the negative side of the line. The starting band of the tube is connected across the two terminals 7 and 4 of the starting switch. The current which flows through the starting switch and shifter inductance

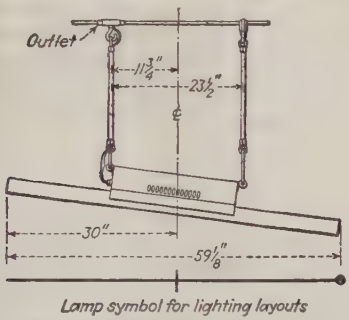


FIG. 47.—Showing essential dimensions and layout of lamp suspension for Cooper-Hewitt alternating-current lamp.

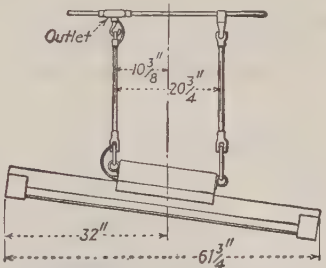


FIG. 48.—Showing essential dimensions and layout of lamp suspension for Cooper-Hewitt direct-current lamp.

coils energizes the magnets of the inductance coils so that the starting switch is rotated. This rotation of the starting switch breaks the mercury contact inside the switch. This interruption of the current produces a momentary high induced voltage on the starting band of the lamp tube. The high induced voltage forms a "hot spot" of electric discharge on the mercury pool in the lamp tube, vaporizes some of the mercury, and allows current to pass through the lamp tube from the positive side of the line to 1 and 2, through the tube to 3 and 4, through the shifter inductance coils to 5, and through the stabilizing resistance to the negative side of the line. If the shifter-current interruption does not at first start the lamp, the above operations are repeated, until the lamp is lighted. As soon as the lamp lights, the main current flowing through the shifter inductance coils holds the mercury starting switch in its open position.

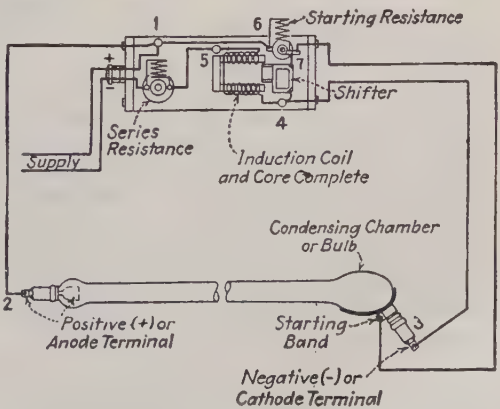


FIG. 49.—Wiring diagram of a direct-current Cooper-Hewitt lamp.

108. Operation of A-c, Mercury-vapor Lamp.—The mercury vapor in the tube of the mercury-vapor lamp will allow current to pass through the tube in only one direction. In order to give steady and efficient operation on alternating current, mercury-vapor lamps are provided with two anodes connected in series with stabilizing resistances to the outside secondary terminals of an autotransformer, whose primary terminals are connected to the a-c supply circuit (Fig. 50). The center point of the autotransformer secondary is connected through the shifter inductance

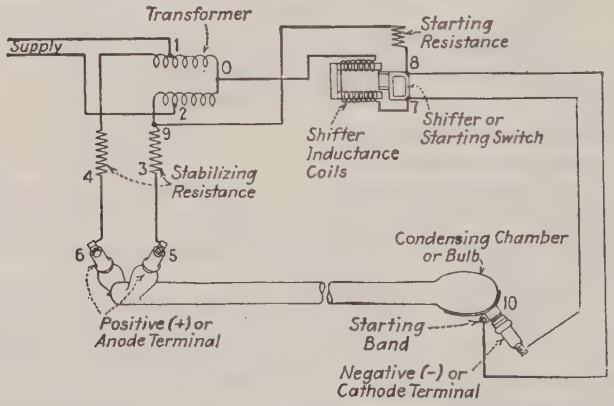


FIG. 50.—Wiring diagram of an alternating-current Cooper-Hewitt lamp.

coils to the cathode terminal of the tube. The primary circuit of the transformer is always, 1, 0, 2. During one half cycle the secondary current flows from 0 through the shifter inductance coils to 7, to 10, through the tube to 5, through the stabilizing resistance to 2, and back to 0. During the other half cycle the secondary current flows from 0, through the shifter inductance coils to 7, to 10, through the tube to 6, through the stabilizing resistance to 1, and back to 0. The current thus flows through the tube always in the same direction throughout the complete cycle of alternating current in the primary circuit of the transformer. The lamp is started by means of the auxiliary mercury starting switch in the same general manner as the d-c lamp.

109. Maintenance Table for Cooper-Hewitt D-c Lamps

Trouble	Cause	Remedy
Tube does not start but flashes white between electrodes	1. Tube may be a poor starter 2. There may be a poor or loose contact in the auxiliary, at the lamp terminals, in the separable connector, at the line switch, or in the block fuse	1. Shake the tube slightly 2. Rotate the tube slightly in clamps until negative tip is changed a little, not more than ½-in. from the normal position 3. Examine vacuum 4. Examine the auxiliary switch, fuse block, and separable connector for poor contact
Tube does not start but flashes red	Vacuum is impaired	Tube must be replaced
Tube does not start or flash, but shifter operates	1. Vacuum of shifter is impaired, and it flashes red, or mercury mirrors the inside 2. Vacuum of tube is impaired 3. Impaired insulation 4. Tube static due to near-by belts or friction of the mercury in a tube handled and not since operated	1. Replace shifter 2. Replace tube 3. If impossible to locate and remedy, return auxiliary for repairs 4. Ground belts by means of grounded metal belt combs and wipe lamp tube with a wet cloth
Tube does not light, and shifter does not operate	1. Shifter sticks in its ports 2. Resistance unit is burned out 3. Electric supply is interrupted in either the main or the shifter circuits	1. Inspect shifter 2. Replace resistance unit 3. Look for cause of interruption in circuit, switches, and fuses, using a voltmeter or test lamps
Lamp runs above normal candle power and tube blackens quickly	1. High lamp current because of high voltage 2. Defective resistor	1. Measure line voltage; if above 125 volts, correct 2. Examine resistor and replace if necessary
Lamps run below normal candle power, flicker, or drop out	1. Supply voltage is too low 2. Poor contact in some electrical connection	1. Ascertain exact line voltage 2. Inspect all electrical connections in auxiliary and to lamp tube

110. Maintenance Table for Cooper-Hewitt A-c Lamps

* Trouble	Cause	Remedy
Tube does not start but flashes white between electrodes	1. Tube may be a poor starter 2. There may be a poor or loose contact in the auxiliary, at the lamp terminals, at the line fuse switch, or in the block	1. Shake tube slightly 2. Rotate the tube slightly in clamps until negative tip is changed a little, not more than ½ in. from the normal position 3. Examine vacuum 4. Examine the auxiliary switch and fuse block for poor contact
Tube does not start but flashes white between negative and one positive electrode	1. The other positive electrode is disconnected 2. Resistance unit is burned out	1. Look for the interrupted point in circuit of that positive 2. Replace resistance unit
Tube does not start but flashes red	Vacuum is impaired	Tube must be replaced
Tube does not start or flash, but shifter operates	1. Vacuum of shifter is impaired, and it flashes red, or mercury mirrors the inside 2. Vacuum of tube is impaired 3. Impaired insulation 4. Tube static due to nearby belts or to the movement or friction of the mercury in a tube handled and not since operated	1. Replace shifter 2. Replace tube 3. If impossible to locate and remedy, return auxiliary for repairs 4. Ground belts by means of grounded metal belt combs and wipe lamp tube with a wet cloth
Tube does not light, and shifter does not operate	1. Shifter sticks in its supports 2. Electric supply is interrupted, in either the main or the shifter circuits	1. Inspect shifter 2. Look for cause of interruption in circuits, switches, and fuses, using a voltmeter or test lamps
Lamp runs below normal candle power. Flickers or drops out	1. Supply voltage is too low 2. Wrong connections are made to the transformer 3. Poor contact in some electrical connection	1. Ascertain exact line-voltage variation and connect to proper transformer taps 2. Correct transformer connections 3. Inspect all electric connections in auxiliary and to lamp tube
Lamp runs above normal candle power, and tube blackens quickly	High lamp current because of high voltage and wrong transformer connections	Measure line voltage and correct connections to the transformer
Auxiliary transformer and inductance coils are exceedingly hot and smoke	Short circuit in auxiliary	Look for possible short circuits. If auxiliary has been run long on too high current, the insulation is generally impaired, which would result in poor starting of the lamp
Auxiliary hums excessively	1. Vibration of transformer laminations 2. Vibration of auxiliary cover 3. Vibration of other small parts of auxiliary	1. Tighten the transformer clamps holding the transformer laminations and drive a fiber wedge between core and coils 2. Tighten cover clamps by bending the wire ring 3. Locate the vibrating part and tighten the rivets or screws holding it in place

111. Mercury Mazda Lamps—Luminous-light Type

(General Electric Co.)

Lamp No.	Approx. watt-aget[a]	Outer bulb	Inner bulb	Base	Position of burning	Std. pkg. quan.	Rated initial lumens[b]	Lumens per watt[c]		Rated av. lab. life, hr.	Max. over-all length, in.	Av. light center length, in.	Approx. length of light source, in.
								Rated initial	At 70% rated life				
A-H2	250	T-9, clear	None	Med.	Any	12	7,500[c]	30[c]	25	2,000[d]	8	5	4⅛
A-H1	400	T-16, clear	T-11, Pyr.	Mog.	Base up[e]	6	16,000[c]	40[c]	33	2,000[d]	13	7¾	6
B-H1	400	T-16, clear	T-11, Pyr.	Mog.	Base down[e]	6	16,000[c]	40[c]	33	2,000[d]	13	7¾	6
A-H6	1,000	Water jacket required[f]	T-2, Quar.	Sleeve	Horizontal	6	65,000	65	52	75[g]	3¼	...	1
A-H9	3,000	T-9½, clear	None	S.C. Term.	.....	1	120,000	40	..	2,000	54⅞	...	48

[a] For total, add auxiliary watts.

[b] Approximate lumens and lumens per watt when operating on approved auxiliary equipment at its rated line voltage and frequency.

[c] Initial lumens and lumens per watt apply after 100 hr. of operation.

[d] Burning hours when tested on approved auxiliary equipment at its rated line voltage and frequency and on an intermittent schedule in which lamps are turned off and restarted no oftener than once every 5 burning hours.

[e] Burning position must be within 10 deg. of vertical.

[f] Use only approved-type, water-cooling jackets.

[g] Burning hours when tested on approved auxiliary equipment at its rated line voltage and frequency and on an intermittent schedule in which lamps are turned off and restarted no oftener than once every 25 burning minutes.

112. The type H-1 mercury Mazda lamp (General Electric Co.) consists, essentially, of two main electrodes located at opposite ends of a glass tube in which the mercury that maintains the arc is vaporized (Fig. 51). These electrodes are of tungsten wire, coiled and covered with barium-strontium oxide, which makes it possible for them to function satisfactorily at a correct temperature and for a long useful life.

The arc tube contains a small amount of pure argon gas which is used as a conducting medium to facilitate the starting of the arc before the mercury is vaporized. Near the upper end of the tube is a starting electrode which is electrically connected to the lower electrode, and hence when voltage is applied an electric field is set up between the starting electrode and the upper main electrode, causing an emission of electrons from the active surface of the main electrode. This imparts energy to the gas in the arc tube so that it becomes conducting.

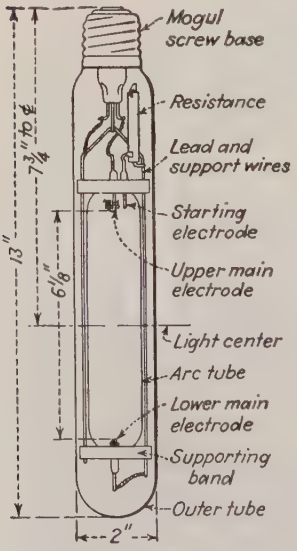


FIG. 51.—Construction details of the type H-1 lamp. (*General Electric Co.*)

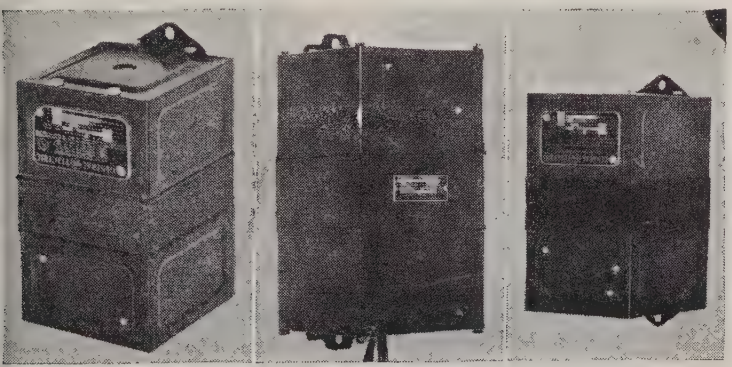
The quantity of mercury in the arc tube is carefully measured so as to maintain quite an exact vapor pressure, which, incidentally, is about normal atmospheric pressure.

The arc tube is enclosed in a larger tubular bulb which makes the lamp less subject to the effect of surrounding temperature. About ½ an atmosphere of nitrogen is introduced in the space between the arc tube and the outer bulb.

Because in most of its applications the lamp will be burned in a base-up position, the majority of these lamps are designed accordingly. They may be obtained, however, for base-down burning, the chief difference being that in a base-down burning lamp the arc tube is reversed so that the sealing tip is still at the top in order not to pocket any of the mercury, since this might interfere with its complete vaporizing. If all the mercury does not vaporize, the pressure of the mercury vapor will be less than normal, resulting in lower efficiency. The lamp must be operated in a vertical position in order to keep the arc stream in the center of the tube. If the lamp is deviated from vertical more than 10 deg. the arc stream will bow until it touches the side of the tube and will quickly melt the glass and ruin the lamp. Horizontal operation requires the use of an auxiliary magnetic deflecting coil to keep the arc stream centered in the discharge tube.

113. At starting of the H-1 lamp a high voltage is applied by means of the transformer auxiliary, and the arc is struck through the argon gas in the bulb. The voltage immediately drops because of the high reactance of the transformer. The argon arc is seen for about 2 min. as a bluish glow that fills the entire arc tube. After a few minutes the voltage rapidly increases until the lamp reaches a stable operating condition in about 7 min., at which time all the mercury is completely vaporized. At this stage the arc no longer fills the tube but is concentrated to a pencil-like arc stream of high intensity.

If the current is interrupted while the lamp is in operation, the lamp cannot be relighted until it has cooled enough to reduce the mercury vapor pressure sufficiently to allow the arc to strike again, which will occur automatically if the current is on. This requires about 7 min. This characteristic of the lamp in some applications is likely to be a disadvantage in intermittent services where lamps are often switched on and off. However, where lamps are used continuously for extended periods, as they are in industrial interiors, no inconvenience is to be expected.



I. H-1. II. Tulamp (H-1). III. H-2.

FIG. 52.—Transformer auxiliaries for mercury lamps. (*General Electric Co.*)

114. Auxiliary equipment for the H-1 lamp consists of a transformer to provide the proper starting and operating voltages (Fig. 52). All transformers have several primary taps (100, 107, 115, and 123 volts) for close adjustment to the installation line voltage, and each is available with or without integral power-factor correction. A transformer with a built-in condenser will result in a power factor of about 90 per cent and in general is to be recommended, but this is not essential in installations where consideration of the power factor is unimportant or where other means of general power-factor correction are in use. A separate transformer may be provided for each lamp, or the tulamp type (Fig. 52, II) may be

used to provide for two mercury lamps. The transformer may b mounted near each individual lamp or, if more convenient, grouped one or more banks and located at a distance from the lamps or at an point along the circuit where it will be inconspicuous (Fig. 53).

115. The H-2 mercury Mazda lamp (Fig. 53*A*) is similar in construc tion and operation to the H-1 lamp except that it has a single bulb (no an outer and inner as in the case of the H-1) and is, therefore more sen

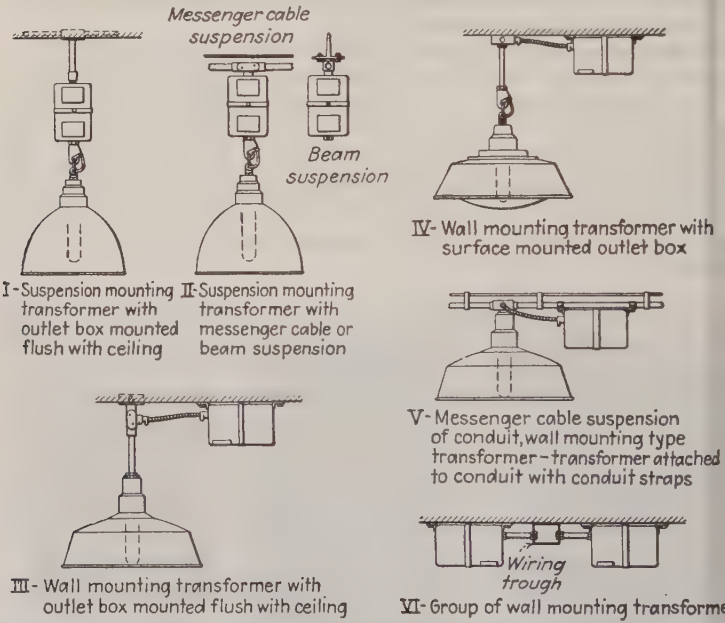


FIG. 53.—Methods of mounting transformers for mercury Mazda lamp (*Westinghouse Electric & Manufacturing Co.*)

tive to moving air. To ensure normal operation this lamp must protected from drafts, and enclosing equipment is therefore recom mended. Having a more diffuse arc stream, it can be burned in an position.

The color of light from the H-2, although similar to that of the H-1, h slightly less of the yellow. The tip of the H-2 is coated to conserve he and keep this end of the bulb hot enough so that no mercury will rema in a condensed form. This is particularly important when the lamp operated base up.

Transformers similar to those for the H-1 lamp as described in Sec. 1 are required.

116. The 1,000-watt, Type H-6 mercury lamp (General Electric Co.) consists of a capillary quartz tube about $1\frac{1}{2}$ in. long having an outside diameter of $\frac{1}{4}$ in. and a bore of $\frac{1}{12}$ in. (Fig. 54). Sealed into each end is a tungsten wire which serves both as electrode and lead. The tips of these wires project just through the surface of a small mercury pool in each end of the lamp. The pressure when not lighted is about $\frac{1}{15}$ atmosphere, which is the pressure of the argon gas with which the lamp is filled. The lamp reaches its full brilliancy in 1 or 2 sec. after power is applied, the heat from the arc quickly vaporizing the mercury and building up the pressure to about 80 atmospheres.

Because of the high wattage in such a small volume, it is necessary that water be passed over the tube fast enough to prevent the formation of steam bubbles on the surface of the quartz tube. To accomplish this, a "velocity tube" is placed around the lamp with a very small radial clearance through which the water must flow. Because the cross section of the water path is so restricted, sufficient velocity is attained to prevent steam formation with a water flow of about 3 qt. per min. Recirculating cooling systems have been built employing a pump and radiator. The temperature of the water increases only a few degrees in passing over the lamps. More than 90 per cent of the infrared (heat) radiation is absorbed by the circulating water, which makes the coolness of its light one of the most valuable characteristics of this lamp. To supply an equal amount of light only 42 per cent as much wattage is required in the water-cooled, quartz H-6 lamp as with a 1,000-watt, tungsten-filament source and with only one-fifth the radiant energy.

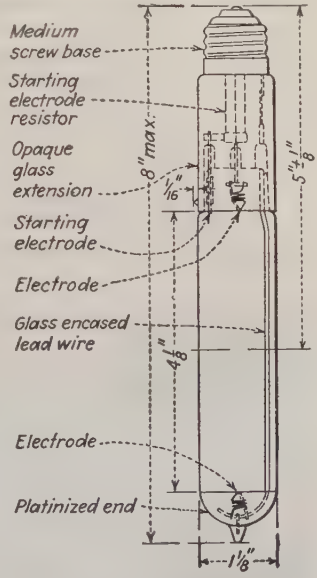
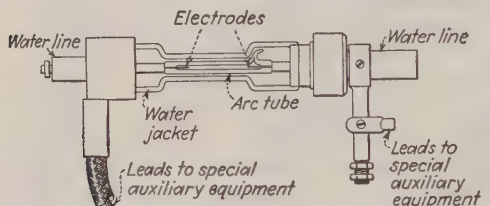


FIG. 53A.—Construction details of the type H-2 lamp. (*Westinghouse Electric & Manufacturing Co.*)

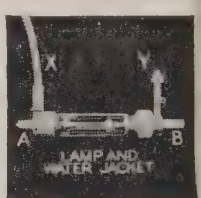
The lamp produces 65,000 lumens with a maximum surface brightness of 195,000 candles per sq. in., one-fifth the brightness of the sun. Because the heat storage is small and cooling rapid, H-6 lamps may be restarted at once after the current has been turned off. During life the lamp voltage gradually increases, and the current and wattage decrease. Either fracture of the quartz bulb or failure to start terminates the useful life of the lamp. It is advisable to include a pressure switch in the control circuit so that the power is turned off automatically if the water

jacket breaks, or if the water supply is interrupted. The auxiliar equipments for this lamp are pictured in Fig. 54, III. The life i dependent upon the number of times the lamp is started and the typ of service.

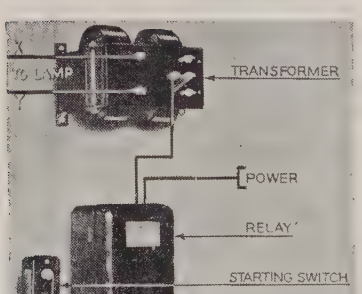
A high-reactance transformer supplies the necessary lamp voltage fo a-c operation. The secondary of the transformer supplies about 1,20 volts on open circuit for starting the discharge, the reactance of th transformer limiting the starting current to 2.6 amp. As the lam



I. Lamp. (*Westinghouse Electric & Manufacturing Co.*)



II. (*General Electric Co.*)



III. Auxiliary equipment and connection diagram. (*General Electric Co.*)

FIG. 54.—1000-watt, H-6, water-cooled mercury lamp.

warms up, the pressure rises, a voltage builds up to 840 volts, an the current automatically drops t 1.4 amp.

Ballast equipment is also r quired for d-c operation. The lam current will be about 15 per cen less than on alternating curren but the d-c supply equipment somewhat more bulky than th transformer.

Several kinds of sockets hav been designed for the H-6 lam holding one, two, or three lam for a variety of intended uses. few of the applications are f motion-picture production, motio picture projection, photoengravin and blueprinting.

116A. The H-9 mercury lamp similar in appearance to a fluore cent lamp and is mounted horizo tally in a luminaire similar to t direct type of fluorescent lighting luminaire. It is intended for very hi mounting where uniform illumination can be obtained with wide spaci between lighting units, such as in airplane assembly plants.

117. Mercury lamps are used in industrial locations where the fine-detail-discerning quality of the type of light is desirable, such as for inspection work in sheet-metal-working plants where imperfections in the metal or in the paint may be easily detected. They may be used by themselves in fixtures as illustrated in Figs. 83 to 86 or in combination with incandescent lamps as in Figs. 87 and 88. Since the color of the mercury light is all yellow-green and blue-violet, it is not desirable to use the lamps by themselves in most locations for general illumination, owing to the fact that colors are not recognizable in their true values, and the sallow appearance of the workmen may be psychologically depressing. Also, the flicker and stroboscopic effect may be objectionable where machinery or objects are in rapid motion. Finally, in the event of a current interruption or overloads on the lines, causing a voltage drop sufficient to extinguish the lamp, it will not relight until it has cooled down to a point where the vapor pressure of the mercury has been reduced sufficiently to allow the arc to be reestablished. Including the time required for the lamp to reach full brilliancy, 10 to 15 min. production time may be lost.

Combination mercury and incandescent lighting eliminates all these defects. The incandescent lamps provide color correction to the light, minimize the stroboscopic effect by providing steady illumination, and provide sufficient illumination to enable work to continue while waiting for the mercury lamps to start. The total illumination will be the sum of that provided by each of the types alone.

118. There are several ways of combining mercury and incandescent lighting.

1. An existing incandescent-lamp installation may have its illumination level and seeing quality increased greatly by adding high-intensity, mercury-lamp fixtures interspersed symmetrically with the incandescent fixtures. The mercury-lamp fixtures should be mounted considerably above the incandescent ones for proper mixing of the light.

2. Alternate incandescent and high-intensity, mercury-lamp fixtures may be used. The mixing of the light is apt to be imperfect with this system unless the units are spaced somewhat closer together than their height.

3. Combination luminaires using one 250-watt, high-intensity mercury lamp combined with two 150-, one 300-, two 200-, or one 500-watt incandescent lamp. This has the advantage that the mercury and the incandescent light are mixed before leaving the fixture, providing a pleasing appearance for the room.

SODIUM-VAPOR LAMP

119. The golden light from the sodium lamp (General Electric Co.) is a product of an electric discharge through an atmosphere of sodium vapor. This color is typical of sodium. The light is monochromatic,

i.e., all one color. It is generated at about three times the efficiency reached in large incandescent lamps, and at relatively low brilliancy.

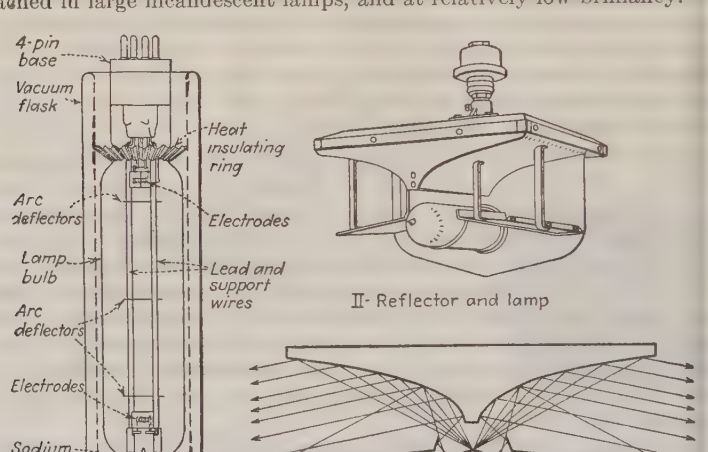


Fig. 55.—Sodium-vapor lamp and reflector.

The lamp consists of a tubular bulb (Fig. 55, I) with electrodes at each end. The leads are brought out at one end and connected to a four-pin base. The lamp contains neon gas at a low pressure for starting, and a quantity of pure sodium. At starting, the electrodes are connected in series through a thermal switch as shown in Fig. 55*A*. After a preheating interval of approximately 1½ min. the thermal switch opens, and the high voltage of the series circuit strikes the arc through the neon gas. The rated arc current is 6.6 amp., requiring a potential of about 28 volts.

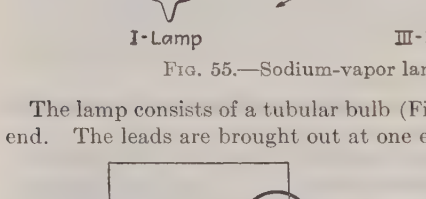


Fig. 55*A*.—Circuit for sodium-vapor lamp.

The light is derived from electronic displacement in the sodium vapor. The entire bulb is luminous, with a brilliancy much less than that of an incandescent filament. The normal operating temperature is about 480°F., which is obtained by conserving heat with an enclosing vacuum flask of glass cylinders; the outer two being sealed together and evacu

ated. This arrangement retains the heat needed to vaporize the sodium, which is normally a solid. When first started, the glow is red—neon color. As heat is stored up, the color gradually becomes golden. It takes about 30 min. to reach full output, although acceptable lighting conditions are reached within a few minutes after starting.

The expected useful life of the lamp is at least 1,350 hr. Neither life nor light output are greatly affected by normal changes of current or surrounding temperature. The power consumption of the lamp itself is about 200 watts, with a power factor of 0.9. The luminous efficiency of the lamp is, therefore, about 50 lumens per watt. The over-all efficiency is reduced to about 40 lumens per watt because of the auxiliary equipment required. This figure may be compared with 15 to 19 lumens per watt obtained from incandescent street lamps.

120. The sodium lamp in its present form is best suited (General Electric Co.) to lighting applications which can use a volume of light about equal to that of a 500-watt incandescent lamp and can use the characteristic golden color and the relatively large physical size of light source; and which also require prolonged burning (as distinguished from short-time intermittent operation) and have an annual total of burning hours such that the saving in energy cost will be sufficient to justify the necessarily higher first cost of equipment. Safety lighting for bridges and highways is just such an application.

Effective use of the light generated is obtained by (1) mounting the lamp horizontally and transversely to the roadway, and (2) by using with it a special combination of reflectors made from Alzak aluminum (Fig. 55, II and III). This material gives high efficiency of reflection and excellent durability under exposure to weather.

NEON LAMPS

121. Neon lamps may be classified into two types: (1) high voltage and (2) low voltage.

122. High-voltage neon lamps (Fig. 56) consist of two terminals or electrodes set into the opposite ends of a glass tube which contains neon, helium, or argon gas, with or without mercury, at low vapor pressure.

Like all gaseous-discharge lamps a higher voltage is required to start the arc than is required for continuous operation. These lamps are supplied from a high-reactance transformer in which the secondary voltage falls rapidly as the current drain is increased. This feature provides the higher voltage required to start the lamp and tends to make the arc circuit stable. Even if the secondary terminals should become short-circuited, no more than full-load current will flow, so that the transformer will not be damaged. A high voltage, 2,000 to 15,000 volts depending on the length and diameter of the tubing and the gas used, is applied to the electrodes at the ends of the tubing by means of this transformer.

The tubing may be made to produce a number of different colors,

depending on the gas used, the color of the glass tubing, and whether or not mercury is added. Table 123 gives the colors available.

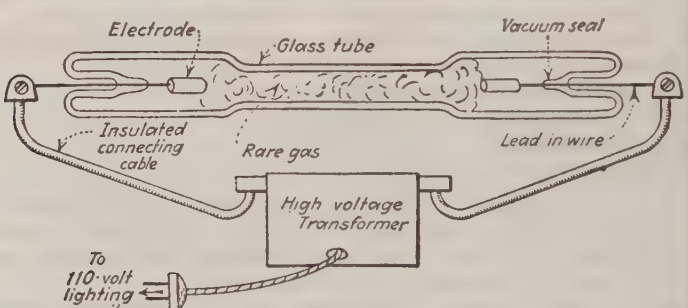


FIG. 56.—Schematic diagram of gas-filled tube and transformer. (*Mille and Fink, "Neon Signs."*)

123. Colors Obtainable from Neon Tubes
(From Miller and Fink, "Neon Signs")

Color produced	Gas used	Mercury used	Color of glass tubing used	Gas pressure mm. of mercury
Standard Colors				
Red	Neon	No	Clear	10 and over
Dark red	Neon	No	Soft red	10 and over
Gold	Helium	No	Soft yellow (noviol)	3
White	Helium	No	Clear	3
Light green	Argon	Yes	Soft canary (Uranium oxide)	8
Medium green	Argon	Yes	Soft yellow (noviol)	8
Light blue	Argon	Yes	Clear	8
Dark blue	Argon	Yes	Soft blue	8
Colors Available but Not Widely Used				
Soft red	Neon	No	Soft opal	10 and over
Orange	Neon	No	Soft yellow (noviol)	10 and over
Soft white	Helium	No	Soft opal	3
Dark green	Argon	Yes	Soft medium amber	8
Red lavender	Neon	No	Soft dark purple	10 and over

124. The gas pressure as given in Table 123 must be determined quit accurately during manufacture. If the pressure is too low, the resistanc of the tubing and the cathode voltage drop will be high, and the tendenc to sputter will be great. Sputtering means that the metal of the elec trode evaporates and deposits on the tube, causing the ends of the tub to blacken. This process lowers the gas pressure still further until th tube flickers and finally fails to light. If the pressure is too high, th light will not be brilliant. The gas pressure may be tested by holding

special type of spark coil (Fig. 57) against either the glass or the electrode wire.

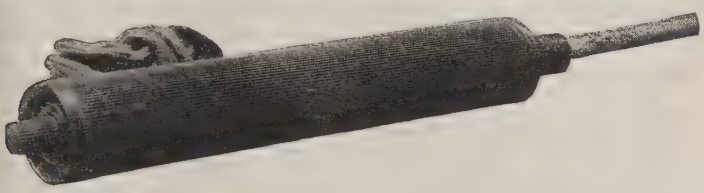


FIG. 57.—A high-tension spark coil for testing the vacuum system. The knob at the end is used to control the intensity of the spark which appears at the metal tip of the device. (*Miller and Fink, "Neon Signs."*)

125. Gas Pressure Determined by Color, Using Spark-coil Tester (Miller and Fink, "Neon Signs")

Coil held against	Color observed	Gas pressure, mm. of mercury	Remarks
Electrode wire.....	Purple	200	Color visible only at edge of electrode shell
Electrode wire.....	Purple	150	Faint glow in tube
Electrode wire.....	Purple	50	Fair glow in tube
Electrode wire.....	Blue purple	15	Dark glow
Electrode wire.....	Red purple	4	
Electrode wire.....	Lavender	2	
Electrode wire.....	Light lavender	1	
Glass.....	Dark blue	0.25	
Glass.....	Light blue	0.10	
Glass.....	Very light blue	0.01	
Glass.....	Blue disappears	0.005	No glow in tube, blue haze near glass wall

126. The principal application of neon lamps is for sign lighting. They are particularly adapted for this class of illumination owing to their bright colors and the fact that the tubes lend themselves readily to the forming of letters and figures. The brilliant single-color red, blue, or green light has an eye appeal in outdoor advertising which white light cannot offer. The orange-red light of the neon tube penetrates great distances, making neon signs stand out with a brilliance and sparkle even on rainy nights. The flexibility of these thin glass tubes in the forming of trade-marks, special figures, and animated designs also adds to their desirability to the advertiser. Finally, the relatively low wattage (about 4 to 6 watts per foot of tubing) makes the operating cost relatively low.

127. The diameter of tubing used is from 7 to 15 mm. (¼ to ⅝ in. These sizes are convenient to work with and thoroughly practical f almost all applications. The voltage required per foot of tubing vari with the diameter of the tubing as given in Fig. 58. The smaller size tubes give the more br liant light but require th greatest voltage per foot tube.

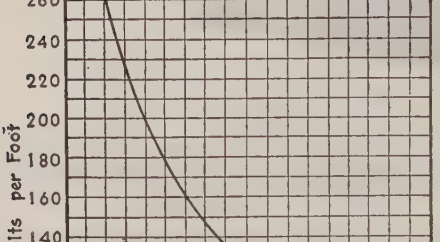


FIG. 58.—The voltage per foot required to operate tubing of various diameters filled with neon gas. (*Miller and Fink, "Neon Signs."*)

128. The transforme are rated according secondary voltage an short-circuit current milliamperes. Table 1 gives a list of standa transformers with th length of tubing in fe which can be supplied b each. This length vari with the diameter of t tubing and the gas use Where it is desired to co bine two different sizes a colors of tubing in series one transformer, the chart of Fig. 59 may be used. Any combination lengths which are side by side in one column in the chart may be used the transformer whose rating is given above the chart.

For example, a 9,000-volt, 30-ma. transformer may supply: (in t first column of the chart) 20 ft. of 15-mm. blue tubing and 16 ft. of 15-m red or (in the third column) 20 ft. of 15-mm. red and 11 ft. of 12-m blue, making a total of 36 ft. in the first case of the larger tubing a 31 ft. in the second case of the combination of the larger and the mediu sized tubing. Note that, as the diameter of the tubing is decreased, t number of feet which can be supplied decreases on account of the rise the voltage per foot, as shown in Fig. 58.

129. In the make-up of signs one section of tubing usually forms tw or three letters. The different sections of tubes are then connected series with wire jumpers until as many feet of tubing have been assembl as can be handled by the transformer to be used, as determined fr Table 130. In large signs several transformers may be used, each co nected to its own section of tubing. The crossovers of tubing betwe letters can be blocked out by winding the tubing with tape and coveri it with a waterproof varnish, or the tubes may be painted with a nc metallic opaque paint. The glass should be made perfectly clean bef painting by rubbing with a wet cloth and drying. Metallic paint (wi lead or copper base) should never be used on the tubing, as it will condu

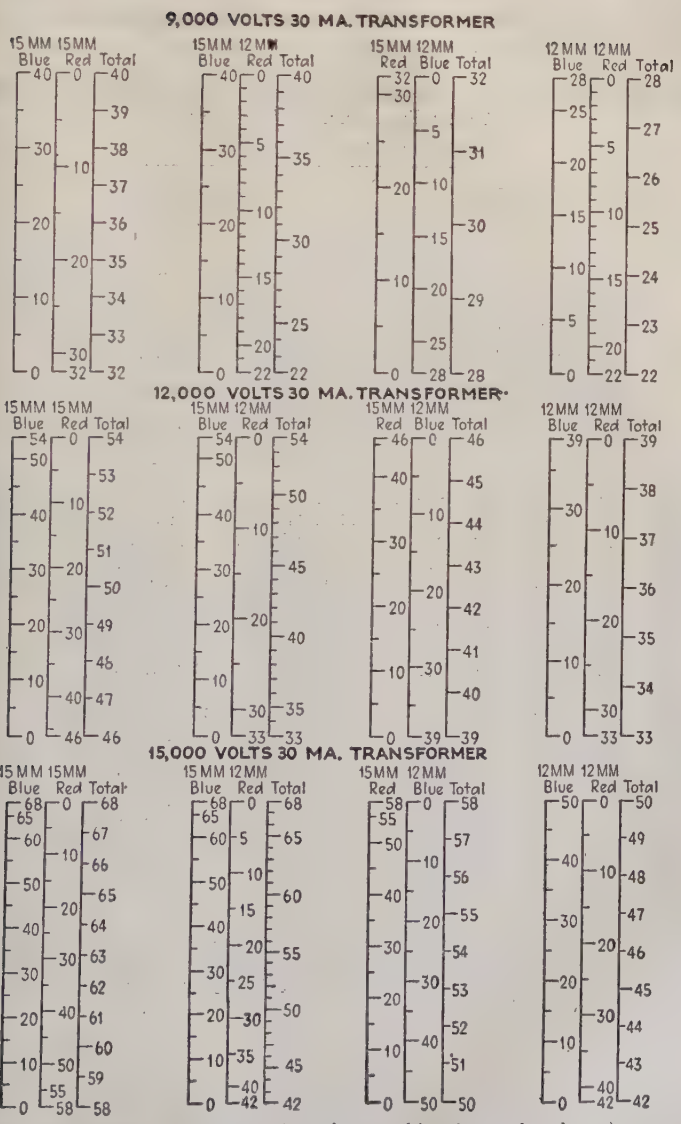


FIG. 59.—Chart for determining the combinations of red and mercury tubing which may be run from a single transformer. (*Miller and Fink, "Neon Signs."*)

electricity and may cause a corona discharge between the tube and th housing which will attack the glass.

130. Transformer Chart, Showing Maximum Number of Feet of Tubin a Given Transformer Will Carry
(Miller and Fink, "Neon Signs")

Transformer specifications					Color of tubing																
					Red						Blue						White or gold				
Secondary volts	Secondary milliamperes short-circuited	Voltamperes	Operating primary watts	Primary amperes, open	Diameter of tubing, millimeters																
					7	9	10	11	12	15	7	9	10	11	12	15	9	10	11	1	
15,000	60	875	400	8.0	...	28	32	36	43	60	...	34	38	44	54	70	..	13	18		
15,000	30	450	210	4.0	...	27	31	34	42	58	...	32	36	42	50	68	9	12	16		
12,000	30	350	175	3.2	...	21	24	28	33	46	...	26	29	34	39	54	7	9	12		
12,000	25	280	145	2.5	...	18	23	25	30	40	...	22	27	31	36	49	..	7	10		
9,000	30	280	130	2.5	...	14	17	19	22	32	...	18	20	23	28	40	..	6	9		
9,000	18	200	80	1.8	9	12	15	17	20	28	11	15	18	20	24	34					
7,500	30	245	100	2.2	...	9	12	15	17	21	...	12	15	18	21	26					
7,500	20	150	72	1.3	7	9	12	15	17	..	8	12	15	18	21						
7,500	18	140	70	1.2	7	9	12	15	17	..	8	12	15	18	21						
6,000	30	170	88	1.5	...	...	9	11	13	17	...	...	11	13	15	22					
6,000	20	130	60	1.1	6	7	9	11	13	17	7	9	11	13	15	22					
5,000	30	160	70	1.4	...	...	8	9	11	15	...	...	9	11	13	18					
5,000	20	100	50	0.9	...	6	8	9	11	15	...	...	9	11	13	18					
5,000	18	95	48	0.8	5	6	8	9	11	15	6	8	9	11	13	17					
4,000	30	130	60	1.1	...	5	6	7	8	12	...	...	8	9	10	14					
4,000	20	75	38	0.6	...	5	6	7	8	..	...	6	8	9	10						
4,000	18	70	36	0.6	...	5	6	7	8	..	...	6	8	9	10						
3,500	18	70	35	0.6	2	3	4	5	6	..	3	4	5	6	7						
3,000	20	55	30	0.5	1.5	2	3	4	5	..	2	3	4	5	6						
2,000	20	45	22	0.4	1	1.5	2	3	4	..	1.5	2.5	3	4	5						

This chart compiled from an average taken from various charts listed by leading tran former companies in the United States. Values given are conservative, to allow fi variations in glass diameters.

131. Neon-glow Lamps

(General Electric Co.)

Watts	Volts	Starting volts below min. marking on base		Current rating amp. at 120 volts	Approx. resistance in base ohms[a]	Bulb	Finish[b]	Screw base	Service[c]	Useful life hr. at 120 volts	Electrode shape	Gas	Overall length, in.	Unit pkg. quan.
		A.c.	D.c.											
3	115–125	60	25	0.030	2,200	S-14	Clear	Med.[d]	A.c.–d.c.	3,000	Round plates	Neon	3 9/32	10
2	115–125	60	25	0.020	3,500	S-14	Clear	Med.[d]	A.c.–d.c.	3,000	Half-round plates	Neon	3 9/32	10
2	115–125	60	25	0.020	3,500	S-14	Sprayed red or yellow	Med.[d]	A.c.–d.c.	3,000	Half-round plates	Neon	3 9/32	10
2½	115–125	60	25	0.025	2,500	S-14	Clear only	Med.[d]	A.c.–d.c.	3,000	Half-round plates	Argon	3 9/32	10
½	115–125	20	..	0.005	3,500	G-10	Clear	Med.[d]	A.c. only	3,000	Cylinder	Neon	1 63/64	10
1	115–125	60	25	0.010	4,800	G-10	Clear	Med.[d]	A.c.–d.c.	3,000	Cylinder and helix	Neon	1 63/64	10
¼	115–125	60	25	0.002	30,000	T-4½	Clear only	Candelabra	A.c.–d.c.	3,000	Hemisphere	Neon	1 ½	10
¼	115–125	40	..	0.003	20,000	T-4½	Clear only	Candelabra	A.c. only	1,000	Hemisphere	Argon	1 ½	10

NOTE.—Normal light output is obtained at voltage range shown. Lamps will operate at reduced light output down to starting voltage shown.

[a] Lamps will be furnished without resistance, only when equipped with double-contact bayonet base of corresponding size at a slight additional cost. S-14 bulb will be equipped with skirted double-contact bayonet base at a slight additional cost.

[b] Lamps listed in clear finish will be supplied with sprayed red or yellow finish at a slight additional cost, except ¼-watt sizes.

[c] On direct current, only one (negative) electrode glows, but gives same candle power as do both electrodes on alternating current.

[d] Will be supplied in skirted candelabra screw base at a slight additional cost.

[e] Supplied in 1-watt size for 210- to 240-volt, a-c or d-c service, Medium screw base only.

132. External Resistor Values for the Use of Neon-glow Lamps on Various Voltages

(General Electric Co.)

Lamp	Line voltage															
	150		200		250		300		350		400		450		500	
	Res., ohms	Wattage rating	Res., ohms	Wattage rating	Res., ohms	Wattage rating	Res., ohms	Wattage rating	Res., ohms	Wattage rating	Res., ohms	Wattage rating	Res., ohms	Wattage rating	Res., ohms	Wattage rating
T-4½ 0.25 watt	17,500	¼	42,000	¼	68,000	⅓	93,000	½	120,000	½	150,000	1	170,000	1	200,000	1
G-10 0.5 watt	9,000	¼	21,000	⅓	33,000	½	45,000	1	58,000	1	70,000	1½	82,000	1½	95,000	1½
G-10; 220V 1 watt	.....	..	.....	..	.....	..	20,000	⅓	32,000	½	45,000	1	58,000	1	70,000	1½
G-10; 110V 1 watt	3,000	½	7,000	1	11,000	3	15,000	3	20,000	3	24,000	5	28,000	5	32,000	5
S-14 2 watt	2,000	1	4,700	1½	7,500	3	10,000	5	13,000	5	16,000	5	19,000	10	21,000	10
S-14 3 watt	1,200	1	2,800	3	4,500	5	6,200	10	7,800	10	9,500	10	11,000	10	13,000	15

Resistor wattage ratings shown are the actual energy to be dissipated. Unless ventilation is good, resistors of double these ratings should be used.

133. Low-voltage, neon-glow lamps (Fig. 60) are operated directly on 110- to 125-volt d-c or a-c systems. They contain two plates to form electrodes spaced with their abutting edges about $\frac{1}{16}$ to $\frac{1}{8}$ in. apart. The bulb is filled with neon gas in some types and argon in others, as indicated in Table 131. A high-resistance coil in the base is connected in series with the electrodes and serves to limit the current, no auxiliary devices being necessary. When the circuit is closed the 110 to 125 volts causes the small air space between the plates to become ionized. A glow discharge takes place between the plates and then spreads so as virtually to cover the surface of the plates. The plates are very rugged and long lived, failure usually being due to the burning out of the series resistance.

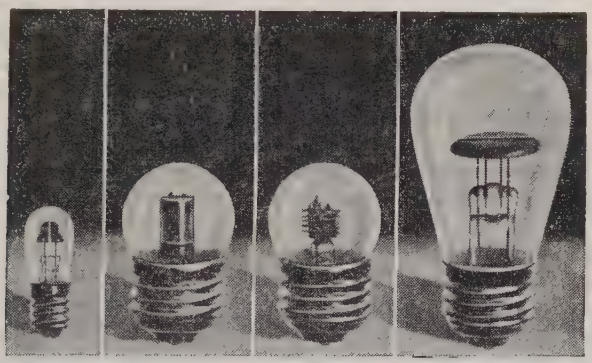


FIG. 60.—Low-voltage neon-glow lamps. (*General Electric Co.*)

When these lamps are used on direct current, only one electrode glows, whereas on alternating current both electrodes glow. They can therefore be used as an a-c–d-c detector device. They are available in three colors: red, green, and blue. They may be used as pilot and indicator lamps in industry, for stroboscopic lamps in the laboratory, and as all-night lights in homes. Their low wattage, long life, and dependability make them ideal for such uses. The characteristics of neon-glow lamps are given in Table 131. When it is desired to use neon-glow lamps on higher voltages than 125, a resistor as given in Table 132 should be used in series with the lamp.

ULTRAVIOLET-LIGHT SOURCES

134. Ultraviolet-light sources are lamps which are designed primarily to produce light of wave lengths in the ultraviolet part of the spectrum (see Fig. 1). It should be understood that all ultraviolet light is not the same. There are at present four recognized bands of ultraviolet light. The band in which the light from any source falls depends upon the wavelength of the light emitted. Each of the recognized bands differs widely from the others in its characteristics, usefulness, and field of application. The four bands are as follows: the near-ultraviolet or fluorescent region, erythemic region, abiotic or bactericidal region, and the Shuman region.

They are listed above in the order of decreasing wave length of the light the wave length of the near ultraviolet being closest to that of visible light. The light from the ordinary fluorescent lamp originates at it source as light in the near-ultraviolet band. This nonvisible light i transformed into visible light by the fluorescence of the coating on th lamp tube under the influence of the near-ultraviolet light. The ligh output from the lamp, therefore, becomes visible light, so that the ordi nary fluorescent lamp is not an ultraviolet-light source. However, b the use of special phosphors for the coating of fluorescent lamps, fluores cent lamps may be made to be sources of ultraviolet light.

The common methods of producing ultraviolet radiations are (1) b carbon and tungsten arcs, (2) by tungsten filaments operated at highe temperatures than in ordinary lamps, and (3) by gaseous-discharge lamp of proper design. Ultraviolet light may be used for heathful radiatio as in the case of the sunlight lamps, for photographic printing, fo illuminating fluorescent materials for analysis or for theatrical effect or for the killing of germs as in the case of the germicidal or sterilamps.

135. Sunlight lamps (Fig. 61) are designed for use in homes an solariums to provide luminous radiation combined with healthful ultra violet rays. There are two types of these lamps: S-1 and S-4. The S- lamp (Fig. 61, I) consists of a tungsten filament in parallel with a mer cury arc. The tungsten filament provides luminous radiation as well a heat to vaporize the mercury. The mercury discharge takes plac between the electrodes at the base of the filament. The filament con tinues to operate after the mercury discharge starts but operates at lower intensity because of the reduction in voltage caused by the high reactance transformer which is built into the base of the fixture wit which this lamp must be used. The mercury arc produces the ultra violet radiation. The bulb is of special glass which transmits biological active ultraviolet rays but absorbs most of the radiation of wave lengt shorter than those in sunlight. These shorter wave lengths are harmf to the eyes. Exposure of the body for a few minutes each day to th ultraviolet rays from these lamps will maintain a healthful tan and he to keep the body in condition to ward off colds and disease during th winter months, when very little of the ultraviolet rays from the sun a available.

The S-4 lamp (Fig. 61, II) consists of a mercury-arc discharge in capsulelike quartz tube. The tube has main electrodes at the top an bottom and an additional starting electrode at the top close to the ma electrode. The tube contains argon gas and mercury. At starting, t arc discharge takes place between the top main electrode and the startin electrode. A resistor in series with the starting electrode limits t starting current. Since there is a considerable drop in voltage throug the resistor, the voltage between the main electrodes is much higher th the voltage between the starting electrode and the top main electrod Therefore the arc spreads to the main electrodes, filling the tube. T voltage is then reduced owing to the high-reactance transformer us

with the lamp, and the current through the starting electrode is limited by the series resistance to an inappreciable value. The quartz tube operates at high pressure. A cooling period of 2 or 3 min. is required before the lamp will restart after a current interruption. The outer bulb of the lamp serves merely as a protective enclosure. The S-4 lamp has about the same ultraviolet output as the S-1 but is the newer lamp of

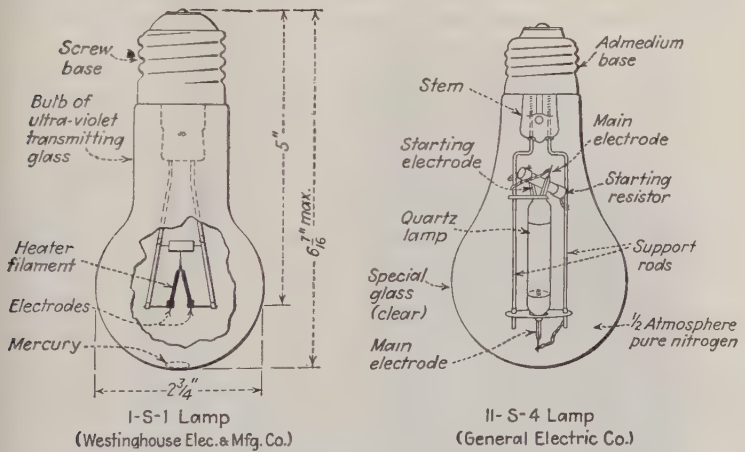


FIG. 61.—Sunlight lamps.

the two and operates at only one-fourth of the wattage of the S-1. The S-4 lamp, whose life depends on the frequency of starting, has a considerably shorter life than the S-1 when used in the usual way of a few minutes' operation at a time. The following table gives the principal data for these lamps.

Lamp no.	Approx. wattage[a]	Bulb	Base	Std. pkg. quan.	Rated life, hr.	Max. over-all length, in.
S-1	400	PS-22, inside frosted	Mogul	6	400	6 7/16
S-4	100	A-21, clear	Admedium	6	[b]	5 5/8

[a] For total, add auxiliary watts.

[b] The life of this lamp cannot be adequately expressed in hours owing to the fact that its total useful burning hours are largely determined by the number of lamp starts involved. Based on laboratory tests, the service life in ordinary household usage has been estimated as approximately 400 applications.

A new phosphor, which will produce the ultraviolet rays required for sunlamps, has been developed for fluorescent lamps. These fluorescent sunlamps are not yet on the market but will become available as soon as manufacturing facilities are developed.

136. Characteristics of Mercury Ultraviolet Lamps

Lamp No.	Approx. wattage[a]	Outer bulb	Inner bulb	Base	Position of burning	Std. pkg. quan.	Rated initial lumens[b]	Lumens per watt[b]		Rated av. lab. life, hr.	Max. over-all length, in.	Av. light center length, in.	Approx. length of light source, in.
								Rated initial	At 70 % rated life				
A-H4	100	T-10 clear	T-3 Quar.	Admed.	Any	6	3,500[c]	35[c]	28	1,000[d]	5⅝	3 7/16	1
B-H4	100	T-16, red purple	T-3 Quar.	Admed.	Any	6	(For fluorescence)			1,000[d]	5½		
C-H4	100	PAR-38, clear	T-3 Quar.	Admed. skirted	Any	6	3,500[c]	35[c]	28	1,000[d]	5¾		
A-H5	250	T-14; clear	T-3 Quar.	Mogul	Any	6	10,000[c]	40[c]	..	1,000[d]	8	5	
B-H5	250	T-14; clear	T-3 Quar.	Admed.	Any	6	10,000[c]	40[c]	.	1,000[d]	8	5	

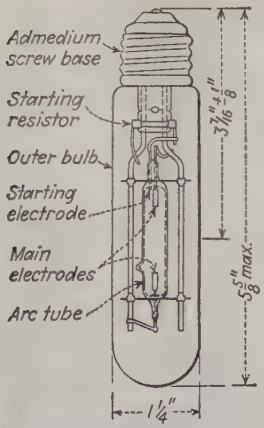
[a] For total, add auxiliary watts.

[b] Approximate lumens and lumens per watt when operating on approved auxiliary equipment at its rated line voltage and frequency.

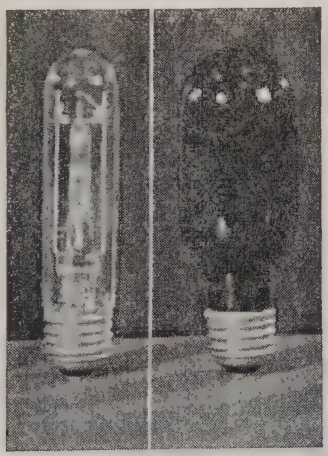
[c] Initial lumens and lumens per watt apply after 100 hr. of operation.

[d] Burning hours when tested on approved auxiliary equipment at its rated line voltage and frequency and on an intermittent schedule in which lamps are turned off and restarted no oftener than once every 5 burning hours.

136A. Ultraviolet Projection and Photographic Lamps.—The H-4 and H-5 lamps (Fig. 62) are identical in interior construction and operation with the S-4 sunlight lamp. They have different bulbs, however, and are used for the projection of ultraviolet light for photographic printing or for theatrical effects. These lamps are sources of light in the erythemic band. The types differ from each other in the amounts of visible light which accompanies the ultraviolet and in the particular range of the ultraviolet light produced. The difference in the characteristics of



I. A-H4 lamp. (*Westtinghouse Electric & Manufacturing Co.*)



II. H-5 lamp. (*General Electric Co.*) III. B-H4 red-purple lamp. (*General Electric Co.*)

FIG. 62.—Types H-4 and H-5 mercury Mazda lamps.

the light emitted from the lamps is controlled by the type of glass used in the bulb of the lamp. H-4 lamps are put into three classes, according to the type of bulb, and the classes are designated by the letters A, B, or C prefixed to the H-4.

The A-H4 lamp (Fig. 62, I) has a clear tubular bulb and is used principally in photographic printing equipment. The B-H4 (Fig. 62, III) has a red-purple bulb which screens out the visible light but allows the ultraviolet to pass through. This lamp is used with projectors to illuminate fluorescent materials for theatrical effects. The C-H4 has a parabolic-shaped clear bulb similar to the one shown in Fig. 32, I, and is used for projecting ultraviolet light without the use of special reflecting equipment. The H-5 lamp (Fig. 62, II) has a higher rating (250 instead of 100 watts) than the H-4 but is otherwise similar. It is made in two types which differ only in the type of base: the A-H5 with a mogul base and the B-H5 with an admedium base. Both types have a clear tubular bulb.

They are used for photographic printing work. If used with a red-purple screen a much larger amount of ultraviolet light is available for illuminating fluorescent materials for theatrical effects than the B-H4 lamp provides. Table 136 gives the principal data for the ultraviolet types of mercury Mazda lamps.

Fluorescent lamps containing a special phosphor whose radiation peaks around 3,600 A in the near-ultraviolet region of the spectrum are now

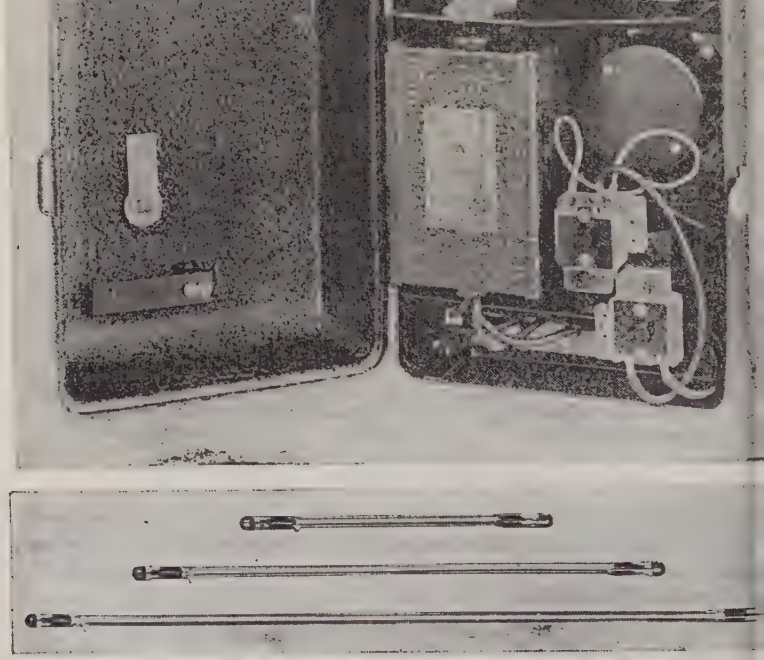


FIG. 63.—Sterilamps. (*Westinghouse Electric & Manufacturing Co.*)

available. Designated as "360BL" lamps, these sources are similar to comparable sizes of standard lamps except for the phosphor; they operate from standard auxiliary equipment. They can be used for blueprinting and for activating luminescent materials such as on fluorescent maps markers, sketches, directional signs, laundry marking, etc. Some visible light is produced. Supplementary filters for absorbing the visible light are available. Fluorescent lamps of this type are available in 6-, 15-, 30-, and 40-watt sizes.

137. Germ-killing lamps, which are called sterilamps by the Westinghouse Electric & Manufacturing Co. (Fig. 63), and germicidal lamps by the General Electric Co. have been developed for use in many places for sterilizing and prevention of mold. The germ-killing lamp is a gaseous-discharge lamp consisting of a long tube containing mercury vapor and inert gases. It gives out ultraviolet radiation in the bactericidal band which kills bacteria of many kinds. The Gerneral Electric 5-watt size may be operated in an ordinary socket, but all the others require auxiliary control equipment, such as a reactor, transformer, relays, etc.

138. Technical Data for Germicidal Lamps
(General Electric Co.)

Characteristic	15-watt (same as fluorescent)	5-watt	3-watt
Over-all length, in.	17 25/32	7 5/8	5 3/8
Diameter, in.	1	1 1/4	1/2[c]
Operating voltages	110–125 volts, 60 cycles	110–125 volts, 50–60 cycles	110–125 volts, 60 cycles
Nominal lamp amperage	0.27	0.048	0.050
Wattage, including reactor	19	5	4
Life, hr.	1,500	1,500	1,000[b]
Ultraviolet output	15–20 microwatts per sq. cm. of 2,537 A at 1 m.	1 microwatt per sq. cm. at 1 m.	3 to 4 microwatts per sq. cm. at 1 m.
Base	F-A1 cap	Medium screw	Radio No. 4108
Operating auxiliary	Same as for 15-watt T-8 fluorescent lamp	None required	Z-11202 reactor
Burning position	Any	Any	Any
Bulb	T-8	T-10	T-4[c]
Standard package quantity	24	24	12

[a] The General Electric Co. can also supply two other types of sterilizing units. The one generally known as the cold-cathode type is available in the 10-, 20-, and 30-in. sizes, the rating being approximately 6 to 10 watts.

The Uviarc is available in sizes from 250 to 1,200 watts. These are the quartz mercury arcs generally used in the medical profession, and in commercial devices for the sterilization of water, the vitamization of food products, and a variety of photochemical reactions.

These units require special sockets and auxiliary devices. Information on these two types of sterilizing units and their auxiliary equipment can be obtained from the Lamp Department, General Electric Co., Nela Park, Cleveland, Ohio.

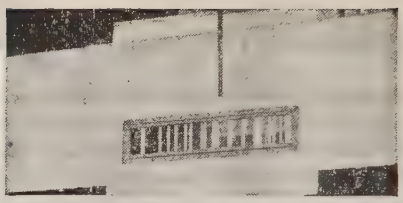
[b] A conservative estimate. Tests not yet completed.

[c] Bent-tube or "closed-hairpin" construction makes lamp approximately 1-in. wide.

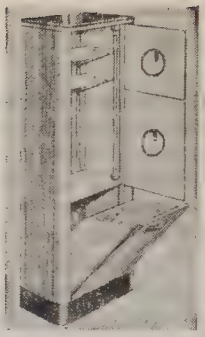
139. The principal uses (Fig. 64) for germicidal and sterilamps are.

1. For storage and aging of meat. The meat when exposed to ultraviolet radiation may be kept in a warm, high-humidity atmosphere where it will age and become tender much more rapidly with no formation of mold or slime and with no loss of weight due to drying out.

2. For irradiation of bread dough to prevent the formation of mold.

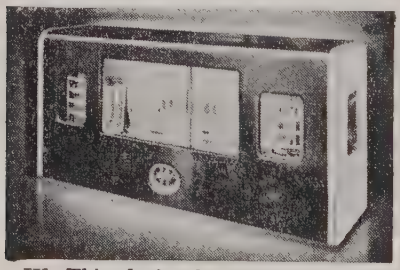


I. Germicidal lamps properly installed and in sufficient quantities can make air delivered from air ducts practically free of bacteria.



II. Sterilized instruments, bandages, and other articles can be kept sterile by the energy from germicidal lamps installed at the opening of the cabinet or container.

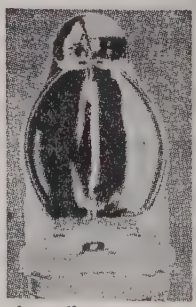
III. The use of germicidal lamps in walk-in coolers and refrigerated display cases is being tested with a view to retarding growth of molds and bacteria.



IV. This device is of the conveyor type. The glasses are placed on the moving conveyor and conducted through a field of radiation produced by the sterilamps. (*Hobart Manufacturing Co.*)

V. Curing of meat.

VI. Seat being sanitized when not in use.



VII. Guard removed showing installation of sterilamp.

FIG. 64.—Applications for germicidal and sterilamps

3. For sterilizing drinking glasses, hospital instruments, toilet seats, etc., to prevent the spread of disease.

4. For use over the hospital operating table to prevent wound infections after major operations.

140. Sterilamp Characteristics
(Westinghouse Electric & Manufacturing Co.)

Characteristic	WL-782-10	WL-782-20	WL-782-30
Over-all length, in	14½	24½	34½
Effective length, in	10	20	30
Maximum diameter, in	⅞	⅞	⅞
Starting voltage, a-c	400	575	750
Operating voltage (approx.)	275	375	475
Operating current (range), amp	0.030–0.050	0.030–0.050	0.030–0.050
Effective life, months	6	6	6

INFRARED HEATING LAMPS

141. Heating or drying lamps are incandescent lamps with filaments which operate at a lower temperature (2500°K. instead of about 3000°K.)

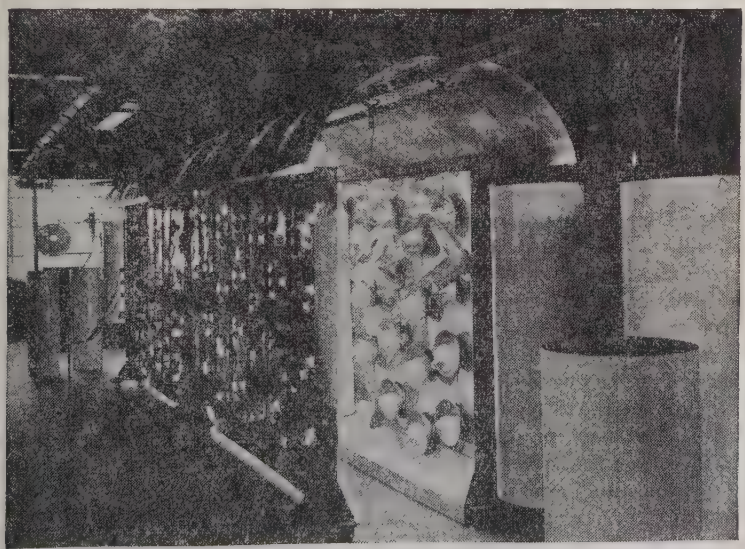


FIG. 65.—Drying lamps in tunnel for drying lacquered automobile bodies.

so that most of the radiation occurs in the infrared part of the spectrum with wave lengths longer than those of visible light. Their principal

use is in ovens for drying and baking enameled and lacquered articles such as automobile bodies (Fig. 65). A bank of these lamps, properly spaced close together and located at from 6 to 18 in. from the surface to be dried, will dry in a few minutes painted articles which would otherwise require several hours. These lamps are made in 250-, 500-, and 1,000-watt sizes as listed in Table 142. The 250-watt size is made in both a pear-shaped bulb and in a reflector-type bulb which may be used without a reflector. Goldplated reflectors, which have a high reflection factor for the infrared rays, should be used with drying lamps.

142. Drying Lamps
(General Electric Co.)

Wattage	250	250	500	1,000
Bulb[a]	PS-30	R-40	G-40	G-40
Volts	105–120	105–120	100–110 110–120	100–110 110–120
Base	Medium screw	Medium screw	Medium Bipost	Medium Bipost
Finish	Clear	I.F. and reflecting neck	Clear	Clear
Light center length, in.	6	.....	3½[b]	3½[b]
Max. over-all length, in.	8⅛	6½	7¼	7¼
Standard package quantity	60	12	12	12

[a] For meaning of bulb symbols, see Sec. **55**.

[b] The light center length of this lamp is the distance from the center of the light source to the plane of the bottom of the bulb (exclusive of tip).

LUMINAIRES

143. Purpose of Luminaires.—A luminaire is a device which directs, diffuses, or modifies the light given out by the illuminating source in such a manner as to make its use more economical, effective, and safe to the eye. The luminaire includes the fixture stem and canopy, the reflector, the lamp socket, and the enclosing glassware. Since the light from a bare lamp is given off approximately equally in all directions, in order to use the light economically some accessory is required to direct the light to the desired areas. As most lamps have a high brilliancy, it is desirable in producing satisfactory illumination that the eye be shielded from the source in order to eliminate direct glare. It would not be possible to illuminate an area with bare lamps, unless an excessively large number of closely spaced units were employed, without the production of dense deep shadows. In many cases the artistic appearance of the illuminating system is of great importance, so that the luminaire must possess decorative features as well as those necessary for satisfactory illumination.

An unshaded incandescent lamp should never be tolerated under any circumstances, unless the bulb is inside frosted, and even then only in such locations as storerooms, etc., where it is desirable to light the entire wall surface, and where the eyes are normally directed away from the location of the lamps. This is because the lamp filament has a high brightness (Table 44), and looking at it continually with the unprotected eye is apt to injure the eye permanently.

144. Distribution Graphs of Luminaires.—The effect of a luminaire in changing the direction and distribution of the light given out by a light source is best expressed by a distribution graph. Figure 66 shows such a graph for a bare lamp and for the same lamp with a reflector. The graph represents the light in a single vertical plane through the center of the light unit, and it is assumed that the light in all similar vertical planes is similarly distributed. See Sec. **31,** How to Read a Photometric Graph.

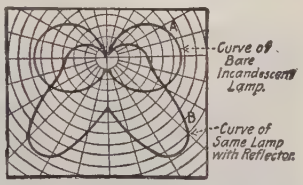


Fig. 66.—Comparison between distribution curve of a bare incandescent lamp with that of the same lamp equipped with a suitable reflector.

Figure 67 shows a sample photometric test report for a 500-watt indirect luminaire of the type shown in Fig. 99. A report of this type is used in comparing luminaires with each other, as to relative distribution of light, type of illumination, lumen-output efficiency, and brightness.

145. Classification of Luminaires.

1. According to system of illumination produced.
   - *a.* Direct.
   - *b.* Semidirect.
   - *c.* General diffuse.
   - *d.* Semiindirect.
   - *e.* Indirect.
2. According to the amount that the luminaire encloses the lamp.
   - *a.* Open.
   - *b.* Enclosed.
3. According to class of service.
   - *a.* Industrial.
   - *b.* Commercial.
   - *c.* Residential.
   - *d.* Street lighting.
   - *e.* Floodlighting.
4. According to the material of which the luminaire is made.
   - *a.* Steel.
   - *b.* Aluminum.
   - *c.* Opal glass.
   - *d.* Prismatic glass.

e. Mirrored glass.
f. Glass and metal.
g. Plastic.

5. According to method of mounting.
   a. Suspended.
   b. Surface mounted.
   c. Built in.

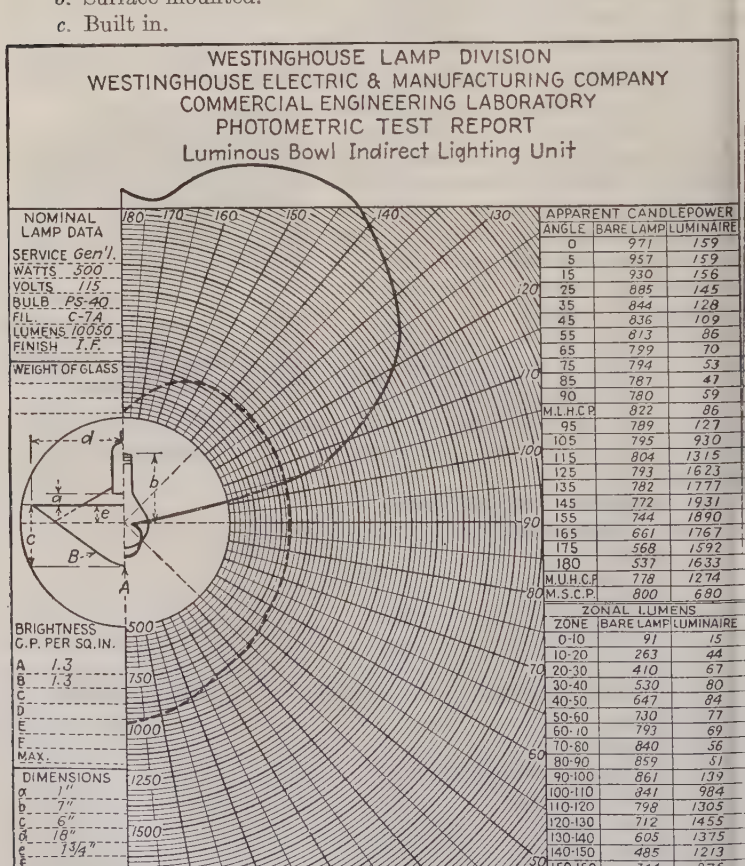
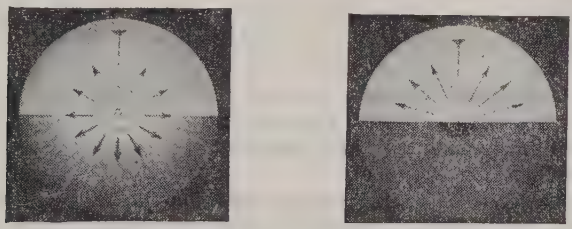


FIG. 67.—Photometric test report. (*Westinghouse Electric & Manufacturin Co.*)

146. Direct lighting can be defined as a lighting system in which practically all (90 to 100 per cent) of the light of the luminaires is directed in angles below the horizontal directly toward the usual working areas (Fig. 68, I). This type of lighting is produced by luminaires, which range from industrial-type steel or aluminum reflectors to fixtures mounted above large light-source areas such as glass panels and skylights. Although, in general, such a system provides illumination on the working surfaces most efficiently, this may be at the expense of other factors such as excessive contrasts of the light source with the surroundings, troublesome shadows, or direct and reflected glare.

I. Direct. II. Semidirect. III. General diffuse.



IV. Semiindirect. V. Indirect.

FIG. 68.—Systems of illumination. (*General Electric Co.*)

147. Semidirect lighting is obtained for the most part from glass luminaires open at the bottom (Fig. 68, II). In this classification 60 to 90 per cent of the light is directed downward to the working surface. This system provides, at low cost, illumination suitable for casual seeing for such areas as corridors, stairways, washrooms, locker rooms, etc.

148. General diffuse lighting refers to the system in which the light emerges from the fixture approximately equally in all directions (Fig. 68, III). The luminaires usually consist of diffusing-glass enclosing globes which may be spherical, diamond shaped, or circular with a flattened surface on the top or bottom. Although this system gives good illumination of better quality than either the direct or semidirect systems, some difficulty may be experienced with brightness and glare. General diffuse lighting has been used in commercial buildings where the greater expense of an indirect system could not be justified.

149. Semiindirect lighting is obtained when some of the light is transmitted directly to the working surface, but considerably more than half (60 to 90 per cent) is emitted upward to the ceiling and upper walls, from which it is reflected diffusely to all parts of the room (Fig. 68, IV). These luminaires may be open at the top or completely enclosed with a dense or enameled glass on the bottom and a clearer glass on the top. The latter type resists the collection of dust and dirt and is easily cleaned. A correctly designed unit has a sufficiently low surface brightness to preclude glare, at the same time transmitting sufficient light through the lower glass to enhance the illumination on vertical surfaces.

150. Indirect lighting, as the name implies, means that nearly all the light (90 to 100 per cent) reaches the work indirectly by being reflected from the ceiling (Fig. 68, V). With the entire ceiling becoming a light source of low brightness, direct glare and shadows are practically eliminated. This produces a quality of lighting highly desirable for drafting rooms and offices where a high level of illumination is needed for doing close work with the least eyestrain.

151. An open luminaire is one which only partially encloses the lamp. Open direct-lighting luminaires have the lamp exposed to view from at least one direction. The luminaires of Figs. 71 to 74 are open-type, direct-lighting units. Open-type luminaires for semiindirect lighting are shown in Fig. 91, and luminaires of the open type for indirect lighting in Fig. 101.

152. An enclosed luminaire completely encloses the lamp from view from any direction. The ones shown in Figs. 75, 77, and 78 are enclosed direct-lighting luminaires. The luminaire of Fig. 95, I is an enclosed unit for semiindirect lighting.

153. Classification of Luminaires According to Class of Service.—Industrial service refers to use in factories and manufacturing establishments. Commercial service refers to use in offices, stores, and public buildings. Residential use means use in houses and apartments; street lighting means the illumination of streets, roads, and highways; and floodlighting means the illumination of outdoor areas such as painted signs, recreational grounds, automobile parking spaces, and building exteriors.

154. Steel-reflectors have a sheet-steel base coated with porcelain enamel, paint enamel, or aluminum paint to form the reflecting surface. The best types of steel reflectors are those coated with porcelain enamel since their reflecting surface is very efficient, permanent, durable, and easily cleaned. Paint-enamel reflectors when new are quite efficient but the reflecting surface deteriorates very rapidly. Aluminum-painted reflectors are slightly better than paint-enamel ones but not so permanent as the porcelain-enamel ones.

Steel reflectors are used in the manufacture of many luminaires of the direct and indirect types.

155. Aluminum reflectors are used in many different types of luminaires. The reflecting surface is usually given an electrochemical treatment called Alzak which removes the impurities from the aluminum and gives it a hard durable surface which has a high reflection efficiency of approximately 90 per cent. Like the steel reflectors, they are used in luminaires for both direct and indirect lighting.

156. Opal glass is a white diffusing glass (Sec. **10**) which transmits light with a loss of only about 15 to 35 per cent, the amount depending on the density of the glass. It breaks up the light rays so that the lamp is not visible and glare is kept at a minimum. Opal glass is used in the manufacture of luminaires of all the various types.

157. Prismatic glass consists of clear glass which is molded into scientifically designed prisms. Each prism is designed with reference to the

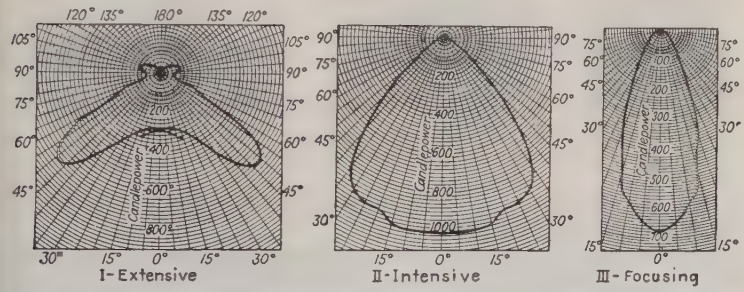


FIG. 69.—Distribution characteristic curves for direct prismatic glass luminaires. (*Holophane Co.*)

position of the light source. By proper design, distribution curves of the extensive, intensive, or focusing types are obtained. The extensive reflector distributes the light over a wide angle below the horizontal (Fig. 69, I), the maximum intensity being at an angle of about 45 deg. with the vertical.

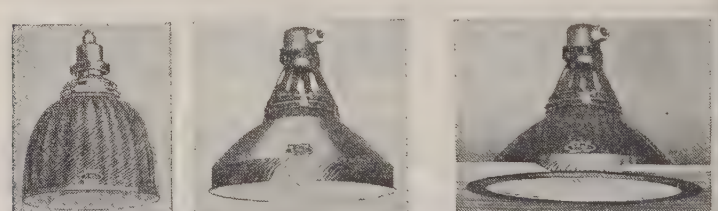
Intensive reflectors (Fig. 69, II) throw the light more directly downward, the maximum intensity occurring between 0 and 25 deg. with the vertical.

Focusing globes and reflectors (Fig. 69, III) concentrate the light to a small area, producing greatest intensity of illumination along the axis of the reflector. Focusing reflectors give an end-on candle power approximately 3½ times as great as the lamp's rated horizontal candle power. The area intensely illuminated is a circle, the diameter of which should be one-half the height of the lamp above the plane of illumination; outside this limit the intensity falls rapidly but not so abruptly as to give the effect of a spot of light. Holophane "focusing" reflectors give their maximum candle powers at about 10 deg. from the vertical.

Prismatic-glass reflectors are used in many direct, semidirect, and semi-indirect luminaires.

158. Mirrored-glass reflectors (Fig. 70) consist of clear glass plated on the back with pure metallic silver. The back of the silvered reflecting surface is protected by some covering in order to prevent deterioration of the reflecting surface. Mirrored-glass reflectors are manufactured for both direct and indirect lighting. Very accurate light control can be obtained with them.

They may be obtained in distributing, semiconcentrating, and concentrating types, the design of which is accomplished by varying the



I. Distributing. II. Semiconcentrating. III. Concentrating.

FIG. 70.—Types of mirrored-glass reflectors. (*Curtis Lighting, Inc.*)

shape of the reflector. These distributions correspond to the three types of prismatic-glass units explained in Sec. **157.**

159. Combination glass and metal luminaires are used for both direct and indirect lighting. The metal part of the unit usually directs the light rays while the glass is used for diffusing the rays in the direct units and for decorative effect in the indirect units.

160. Plastics have been substituted for glass in some of the cheaper luminaires. Since they usually absorb much more light than glass does and are subject to distortion and depreciation from the heat of the lamp, their use is recommended only for casual seeing where the lower first cost is of much more importance than operating results.

161. Suspended mounting refers to hanging the luminaire from the ceiling with a chain, tube, conduit, or cord pendent suspension. Surface mounting refers to placing the body of the luminaire directly against the ceiling. Built-in mounting refers to placing the luminaire in recesses in the ceiling or on the walls or structural members, so that it forms a part of the architectural treatment of the building interior.

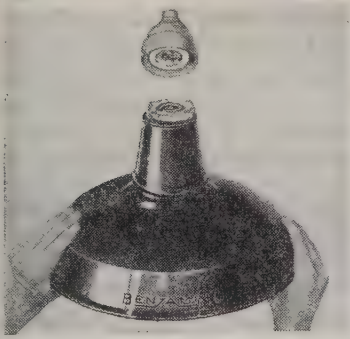
162. Direct-lighting luminaires are manufactured in a large number of types in order to meet the varying requirements for the illumination of industrial and commercial interiors. They are made in types to accommodate incandescent, fluorescent, mercury, and combination of mercury and incandescent lamps. Luminaires for fluorescent lamps are being designed at such a rapid rate that it is difficult to determine which ones will become standardized as the most popular and effective. Since

I. One-piece reflector.

III (*a*). Hood for outlet box cover.

III (*b*). Hood for conduit suspension.

III (*c*). Threaded reflector with separate hood.

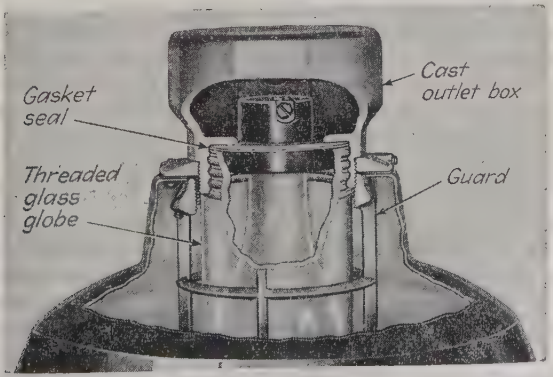


II. Turn-lock type.

IV (*a*). Pendant socket.

IV (*b*). Reflector holder.

IV (*c*). Snap-on reflector.



V. Vapor-proof type.

FIG. 71.—Assemblies of enamelled steel reflectors. (*Benjamin Electric Manufacturing Co.*)

for the same total light output the longer lamps are cheaper both in initial cost for fixtures, wiring, and lamps, and in operating cost for power and lamp replacements, the tendency is to use the 40- and 100-watt lamps with two, three, or four lamps per fixture wherever possible. The over-all cost for an installation with the larger lamps is about 20 to 25 per cent less than with 20-watt lamps. Wherever possible the direct rays of light should be shielded from the eyes by locating the lamps in coves or behind shielding strips or by using louvered glass or metal louvers in front of the lamps.

The more common available types of direct-lighting luminaires are described in the following paragraphs:

1. **Enameled-steel reflector luminaires for incandescent lamps** are made in several different types of assemblies of reflector, socket, and supporting member as shown in Fig. 71. One type, shown in Fig. 71, I, has a reflector and hood pressed in one piece. By loosening the nut at the top, the reflector will slide up on the stem exposing the socket for wiring. This is a weatherproof type for use outdoors and for indoor installation where interchangeability of reflectors and ease of cleaning are not the important considerations. With the turn-lock type of Fig. 71, II, the entire reflector and socket may be removed from the supporting cap by a quarter turn and taken down for cleaning. The prongs of the turn-locking device in addition to supporting the reflector and socket provide the electrical connection from the socket to the circuit terminated in the cap. This type is especially advantageous wherever the cleaning of reflectors in position is going to be difficult. The threaded-reflector type (Fig. 77, III) has a reflector which can be removed from the socket and hood by unscrewing. Several shapes of reflectors will fit the same hoods. Hoods are available with a threaded connection for fixture-stem suspension or with a flange having holes for mounting as the cover of a 4-in. outlet box. With the threaded type the reflectors can be taken down for cleaning, and different reflectors inserted in the same hood, depending on the distribution curve of light desired. The snap-on type (Fig. 71, IV) is designed for fastening on pendent sockets. The reflector holder snaps on the reflector, and then the whole assembly screws onto the threads on the outside of an ordinary brass socket. The vaporproof type (Fig. 71, V) is for interior use in wet atmospheres. It requires a cast outlet box with a threaded opening. The reflector is bolted to a ring which threads on the outside of the box opening. A threaded glass globe screws into the inside of the box opening against a gasket, which seals the box against entrance of moisture. A metal guard is used for low mounting heights or other locations where it is necessary to protect the globe from mechanical injury. The guard screws on the outside of the box opening.

These enameled-steel reflector assemblies are all available in several shapes for specific purposes as shown in Figs. 72 and 73. The flat cone (Fig. 72, I) and the shallow bowl (Fig. 72, II) are used for yard and aisle

lighting for wide distribution of light, where the quality of the light is unimportant and glare from the partially exposed lamp not objectionable. The R.L.M. dome (Fig. 72, III) is a standard dome reflector which must comply with standard specifications of the Reflector and Lamp Manufacturers as regards contour and quality of the porcelain reflecting surface.

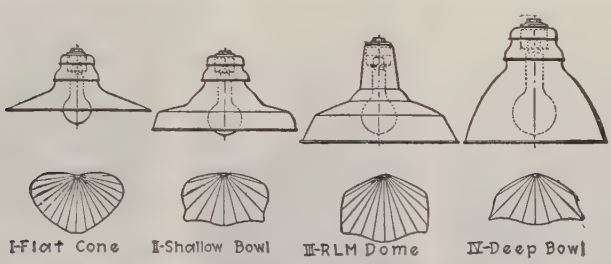


FIG. 72.—Contour outlines of typical enameled-steel reflectors with their characteristic distribution curves.

This type of reflector is the one commonly used for general interior industrial lighting. The deep-bowl type (Fig. 72, IV) is used frequently where the units must be hung very low, as over workbenches. Angle reflectors (Fig. 73) are used in industrial lighting to supplement the overhead units in very high interiors and for special types of service which require very

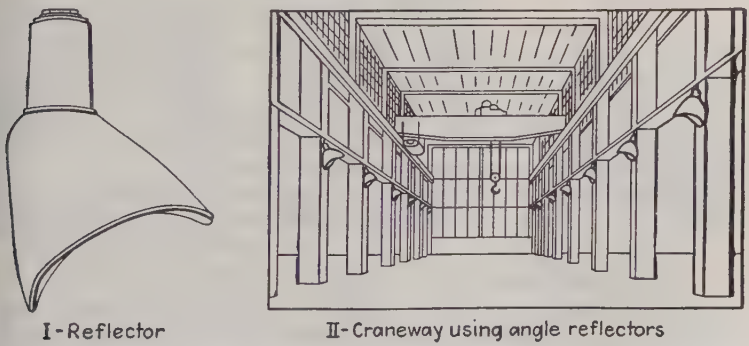
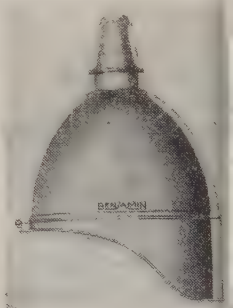


FIG. 73.—Elliptical-angle steel reflector. (*Benjamin Electric Manufacturing Co.*)

good illumination on vertical planes. They are used also for the lighting of billboards and painted signs.

2. **Aluminum luminaires for incandescent lamps** are chiefly of the high-bay type (Fig. 74). They provide more accurate control of light than is obtainable with the enameled-steel reflectors and are recommended where the mounting height is high compared to the width of the area to be lighted. The concentrating type (Fig. 74, I) is used where the units are

sufficiently high so that it is best to locate the units closer together than the mounting height and for high-mounted units in narrow interiors. The spread type (Fig. 74, II) gives better illumination on vertical surfaces and may be used where the spacing is up to 1½ times the mounting



III. Visor attachment.

I. Concentrating type.

II. Spread type.

FIG. 74.—Aluminum high-bay luminaires. (*Benjamin Electric Manufacturing Co.*)

height. The visor attachment (Fig. 74, III) is used where it is desired to cut off the light from one direction. These luminaires are made in the one-piece and in the turn-lock types as described under 1.

3. **The glassteel diffuser luminaire for incandescent lighting** is a combination glass-and-steel direct-lighting unit which is employed for high-quality industrial lighting. It consists of a completely enclosing opal-glass globe (Fig. 75) mounted inside a domé-shaped, porcelain-enameled reflector. The porcelain reflector has the same general construction as the standard R.L.M. dome reflector. Small openings in the top of the dome allow a small portion of the light to be directed to the ceiling. This illumination of the ceiling produces natural and cheerful working conditions whereas with the R.L.M. dome reflectors the ceiling is left in darkness. The enclosing globe of the glassteel diffuser shields the lamp from view and diffuses the

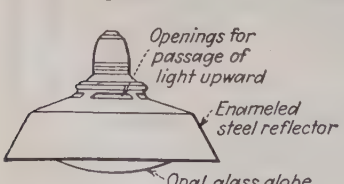
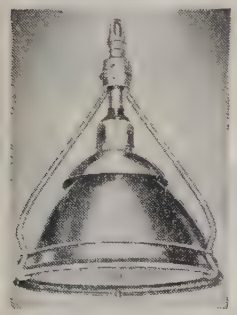


FIG. 75.—Glassteel diffuser.

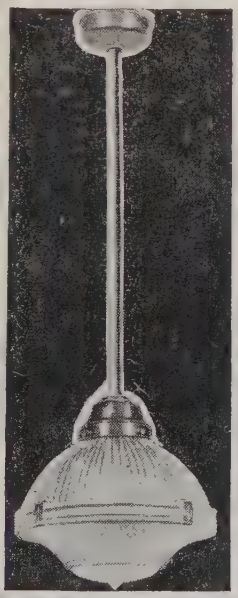
light, reducing the glare effect. The glassteel diffuser is made in all the types of assemblies explained under enameled-steel luminaires.

4. **Direct prismatic-glass luminaires for incandescent lamps** are made in a number of different types as shown in Figs. 76 and 77. The low-bay, open-bottom type (Fig. 76, II) is designed for surface mounting for localized lighting with low ceilings, especially where machines are located in rows with the lights located over the aisles. The type of Fig. 76, IV, is for general lighting with low ceilings. In the suspension types, the high-bay one (Fig. 76, I) is used in the same way as the aluminum high-



I. High bay.

II. Low bay.



III. Suspension.

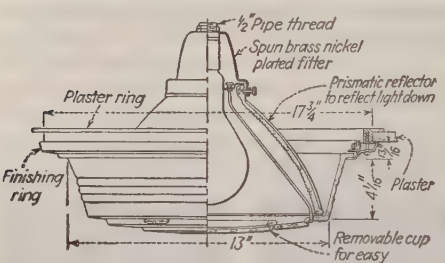
IV. Surface mounted.

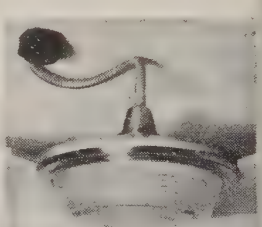
V. Vaporproof.

FIG. 76.—Direct prismatic-glass luminaires. (*Holophane Co.*)

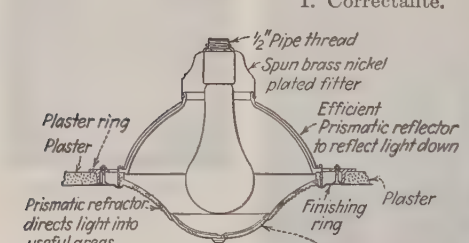
bay type described under (2). The suspension type of Fig. 76, III, is for general lighting with average ceiling heights. The stem has a ball-and-socket joint at the top to allow the unit to align itself so that it will hang plumb. With Types II, III, and IV there is considerable glare, which may be objectionable if the luminaires are in the line of vision. The vaporproof type (Fig. 76, V) has an inner globe which threads into the hood and keeps out moisture. The built-in types shown in Fig. 77 usually have to be provided for with false ceilings, which may make the installation more expensive, but they provide a very good appearance as well as reduce the glare that is inherent in the suspended and surface-mounted types.

Most of the types may be obtained in any one of the extensive, intensive, and focusing classes, as described in Sec. **157.**

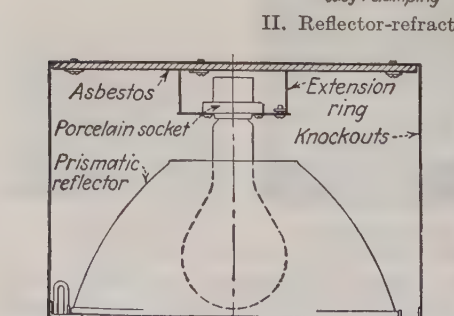


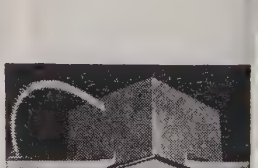


I. Correctalite.



II. Reflector-refractor.



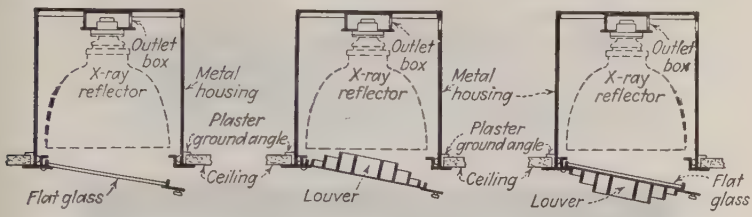


III. Square unit.

FIG. 77.—Built-in direct prismatic glass luminaires for incandescent lamps (*Holophane Co.*)

The extensive types are primarily for lighting moderately small rooms (say 12 ft. square) with a single unit close to or built into the ceiling, or for larger rooms of low ceiling height to enable the use of fewer units of larger size spaced from 1½ to 2 times the mounting height. The intens

sive types are for evenly illuminating large rooms by means of units placed at the ceiling and spaced at 1 to 1¼ times the mounting height. This system is used commonly in industrial plants, restaurants, hotel and club lobbies, and halls of moderate dimensions where the lights are high above the plane of illumination. The classes of lighting for which "focusing" reflectors are designed include the illumination of tables, desks, display windows, store counters (by means of a row of lights placed high and directly over them) and very high rooms (where they are used in the same manner as the intensive type). There are also



I. Mountings.

II. Covers.

FIG. 78.—Method of mounting and covers for mirrored-glass reflectors. (*Curtis Lighting, Inc.*)

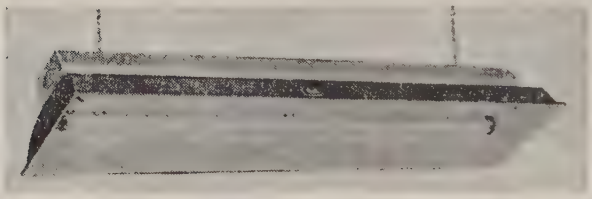
available **asymmetric reflectors** by which most of the light rays are thrown toward one side of the reflector. This is effected by interior vertical prisms which redirect the light from the side where it is not needed.

Asymmetric reflectors are employed for the illumination of show windows, station busses, aisles, passageways, and similar areas.

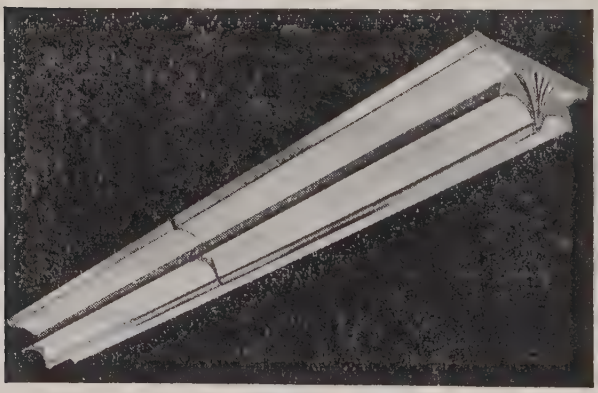
5. **Direct mirrored-glass reflectors for incandescent lamps** (Fig. 70) are of the open-bottom bowl type, usually recessed in a metal housing in the ceiling (Fig. 78). This housing contains an outlet box, on the cover of which the reflector is mounted. The bottom of the luminaire may be left open or may be covered with a curved, crackled glass; a flat sanded glass; metal louvers; or with glass and louver to minimize the glare (Fig. 78).

6. **Enameled-steel reflector luminaires for fluorescent lamps** are shown in Fig. 79. They are supported either by chains as shown in II or by

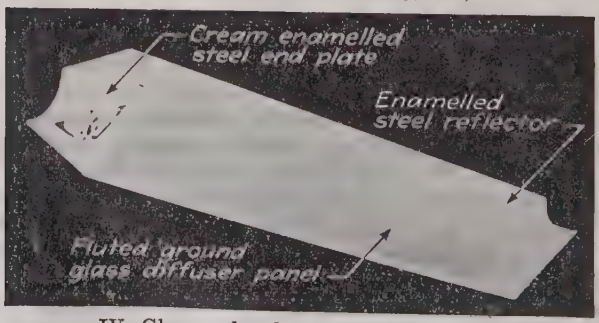
I. Open end. (*Hygrade Sylvania Co.*)



II. R.L.M. (*Miller Co.*)



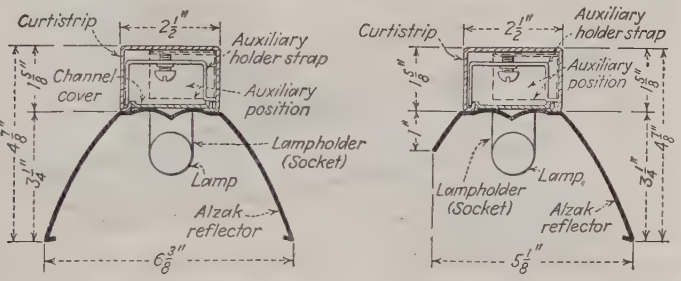
III. Skylux. (*Curtis Lighting, Inc.*)



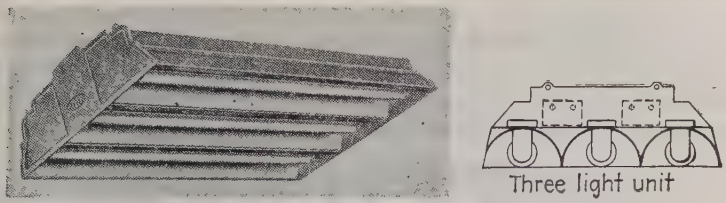
IV. Glass enclosed. (*Barkon-Frink Co.*)

FIG. 79.—Direct luminaires for fluorescent lamps.

conduits. In either case one of the supports must be from an outlet box so that the circuit wires may be brought down. The open-end type (Fig. 79, I) is the cheapest and is satisfactory for ordinary industrial use. The R.L.M. (Fig. 79, II) has been standardized in the same way as the R.L.M. dome for incandescent lamps as described in 1. It is a better quality fixture, and the closed ends present a somewhat neater appearance. The skylux (Fig. 79, III) is designed for commercial use for surface mounting. The direct view of the lamp is cut off by the shield so that glare is minimized. A type for circular lamps provides a



I. Strip type. (*Curtis Lighting, Inc.*)



II. Bench type. (*Miller Co.*)

FIG. 80.—Alzak aluminum reflectors for fluorescent lamps.

decorative unit with an even distribution of light in all directions in the lower hemisphere.

7. **The combination glass-and-steel enclosed type of luminaires for fluorescent lamps** (Fig. 79, IV) gives a well-diffused glareless light for office installations. The fluted glass breaks up the direct rays of light and provides a high-quality appearance for the unit.

8. **Alzak aluminum reflectors for fluorescent lamps** are intended principally for localized lighting. The strip types shown in Fig. 80, I are mounted in continuous lengths, the rectangular section forming a wire-way for carrying the circuit wires and providing a place to mount the auxiliaries. These are used for lighting relatively narrow areas such as showcases, pictures, wall niches behind silhouette signs, etc. The asymmetrical type throws the light to one side. The bench type (Fig.

80, II) is designed primarily for mounting over benches and machines. It is made with concentrating distribution for lighting narrow areas. It is made in types to take any number of lamps from one to four, each lamp being located in its individual recess as shown in the end view.

9. **A combination steel-and-aluminum luminaire for fluorescent lamps** is shown in Fig. 81. It has a steel frame enclosing an Alzak aluminum reflector. The bottom contains egg-crate-shaped louvers which conceal

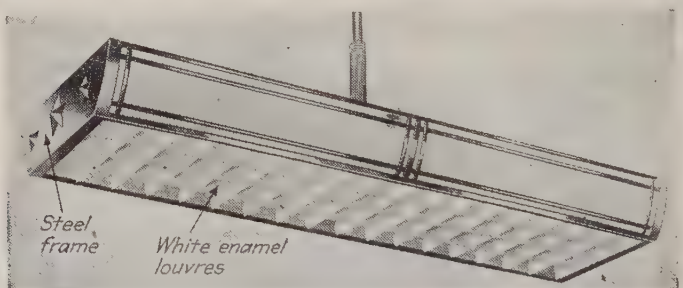


FIG. 81.—Louvered steel luminaire for fluorescent lamps. (*F. W. Wakefield Brass Co.*)

the lamps from view and reduce glare. This unit is intended for store and office use.

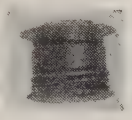
10. **For Cooper-Hewitt mercury-vapor lamps the enameled-steel reflector** as shown in Figs. 43 to 46 is the common type. The standard method of mounting Cooper-Hewitt lamps is by means of a two-point suspension. Various means of supporting are suggested in Fig. 82.

FIG. 82.—Methods of suspending Cooper-Hewitt lamps.

11. **Enameled-steel reflector luminaires for mercury Mazda lamps** are made in several different assemblies as shown in Fig. 83. The unit of Fig. 83, I is the standard type made with the reflector and hood in one piece for conduit suspension. The glass diffusing band minimizes the glare from the mercury lamp. The luminaire of Fig. 83, II is totally enclosed for use in dusty atmospheres. The unit of Fig. 83, III has a reflector which is removable from the socket for easy cleaning. In the disconnecting type (Fig. 83, IV) the whole assembly of reflector, socket, and lamp can be removed from the hood by a slight turn. This provides for easy maintenance.

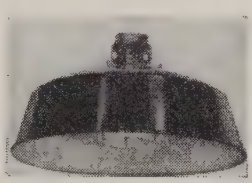
12. **An Alzak aluminum luminaire for mercury Mazda lamps** (Fig. 84) is made for low-bay mounting. It contains a glass diffusing band similar to the one in Fig. 83, I, to minimize glare. It is made in threaded and disconnecting types similar to those of Fig. 83, III and IV.

I. Standard one-piece type.



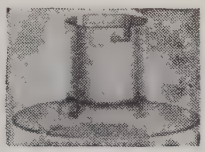
Hood socket for 4-in. outlet box cover mounting.

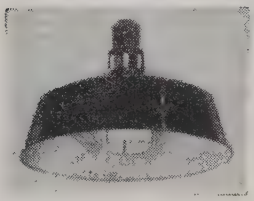
Hood socket for conduit suspension.



III. Threaded two-piece type.

II. Dustproof type.





IV Disconnecting type.

FIG. 83.—Enameled steel direct luminaires for mercury Mazda lamps. (*Miller Co.*)

13. **Prismatic-glass luminaires for mercury Mazda lamps** are made in two types. The low-bay type (Fig. 85, I) is for localized lighting, whereas the high-bay type (Fig. 85, II) is for general illumination with high mounting heights. Both types have a metal cover outside the glass for mechanical protection. The low-bay type has fins on the hood for heat radiation. The high-bay type has a drip cover to protect the lamp from

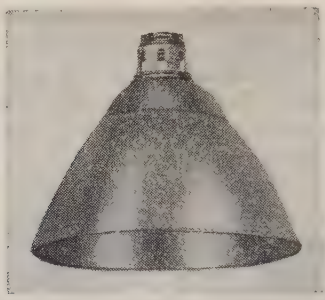
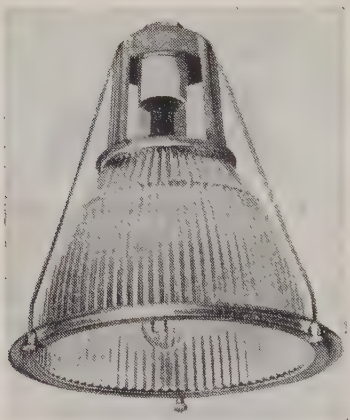
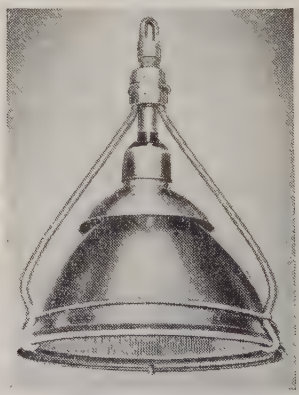


FIG. 84.—Alzak aluminum luminaire for mercury Mazda lamps. (*Miller Co.*)



I. Low-bay type.



II. High-bay type.

FIG. 85.—Prismatic glass luminaires for mercury Mazda lamps. (*Holophane Co.*)

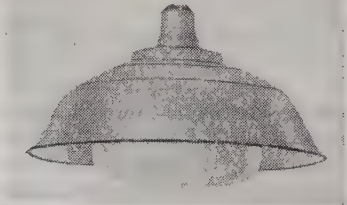
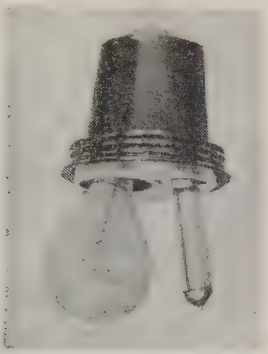


FIG. 86.—Glassteel diffuser for mercury Mazda lamps. (*Miller Co.*)

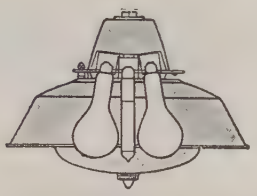
breakage due to rain from monitor windows or roof leaks. The circulation of air around the socket in this type is sufficient for cooling.

14. **The glassteel diffuser for mercury Mazda lamps** (Fig. 86) is similar to the one for incandescent lamps described in (3) except that on account of the length of the mercury lamp the glass bowl is set a little lower under the reflector.



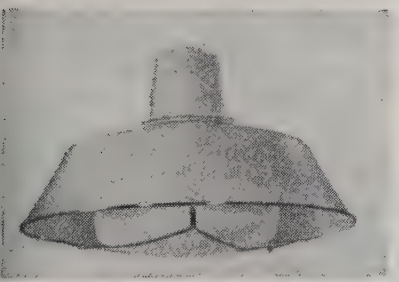
a

Lamp assembly with one incandescent lamp.



a

Lamp assembly with two incandescent lamps.



b

I. Glassteel diffuser. (*Miller Co.*)

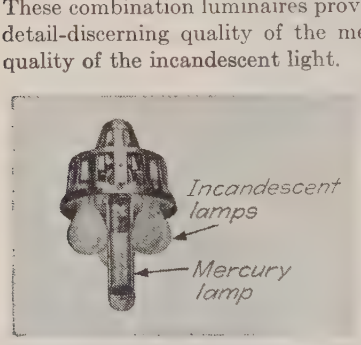
b

II. Dustproof type. (*Benjamin Electric Manufacturing Co.*)

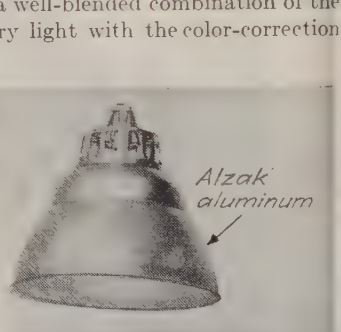
FIG. 87.—Luminaires for combination 250-watt mercury lamp with 1 or 2 incandescent lamps.

15. **Luminaires for combination mercury Mazda and incandescent lamps** are made in several types, as shown in Figs. 87 and 88. For the 250-watt mercury lamp either the glassteel diffuser (Fig. 87, I) or the dustproof type (Fig. 87, II) is used, the latter in dusty locations. Both types are made for use with either one or two incandescent lamps, the

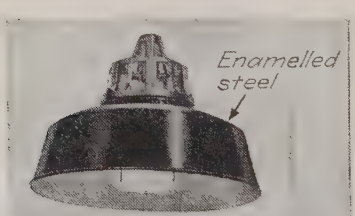
arrangement of which is shown in the figure. With the 400-watt mercury lamp, three incandescent lamps are used as shown in Fig. 88, I. The R.L.M. with glass-diffusing-band dome (Fig. 88, II) is used for general lighting purposes, the high-bay type (Fig. 88, III) for high mountings, and the glassteel diffuser (Fig. 88, IV) for better quality glareless diffusion. These combination luminaires provide a well-blended combination of the detail-discerning quality of the mercury light with the color-correction quality of the incandescent light.



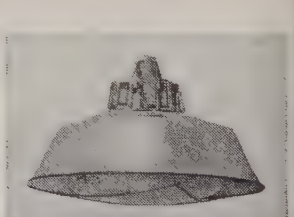
I. Lamp-holder assembly.



III. High-bay type.



II. R.L.M. dome.

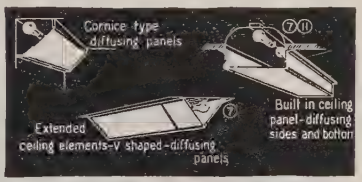


IV. Glassteel diffuser.

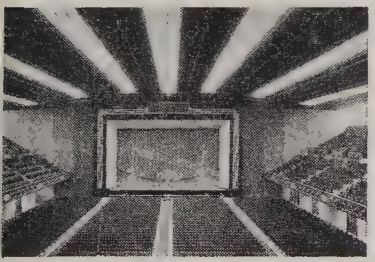
FIG. 88.—Luminaires for combination 400-watt mercury lamp with three incandescent lamps. (*Miller Co.*)

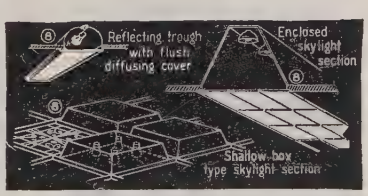
163. Built-in direct lighting, in which the lighting units are recessed in the ceiling, mounted above skylights, or mounted on the surface of ceilings, is used in high-quality commercial locations. In addition to the types of luminaires discussed in Sec. **161,** 4, several methods of locating incandescent lamps behind diffusing-glass panels are used as shown in Fig. 89. The use of bare lamps set in cornices or troughs is illustrated in Fig. 89, I. This provides a bright cheerful atmosphere for a high-class specialty shop. Methods of locating direct luminaires of the types discussed in Sec. **161** behind wide diffusing-glass skylights are shown in parts II and III of the figure. These are particularly applicable to theaters, assembly halls, and large lobbies. Where there is an actual skylight above the artificial skylight a blending of natural with artificial light is possible in the daytime as shown in Fig. 89, III.

164. Semidirect luminaires for incandescent lighting are not very common. The best designed types are shown in Fig. 90. **The prismatic-glass type** (Fig. 90, I) is made in the suspension and surface-mounted types as shown. It is an efficient luminaire for commercial use and creates a bright cheerful atmosphere, although a trifle glary. As shown

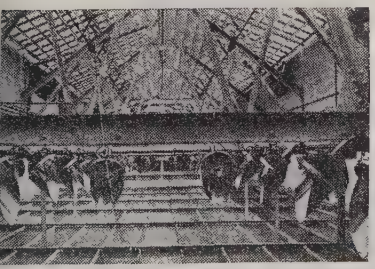


I. Projecting type glass ceiling panels.





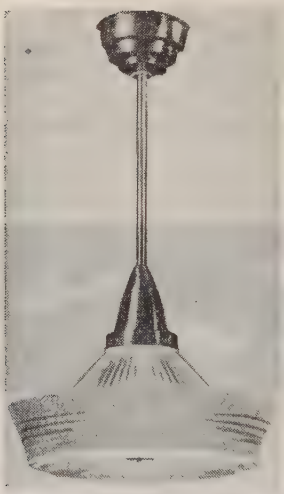
II. Flush type or skylight sections.



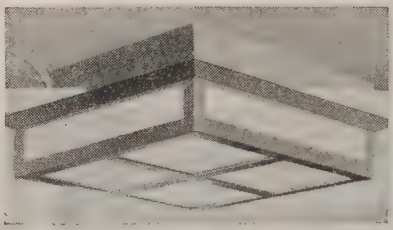
III. Combination skylights, artificial and natural light.

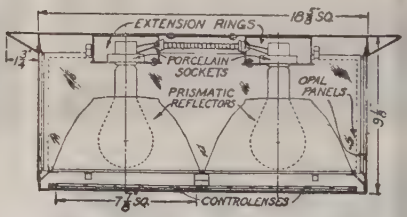
FIG. 89.—Types of built-in direct lighting. (*General Electric Co.*)

n the sectional view the glass consists of two parts: the main prismatic reflector and a bowl-shaped member in the center of which is a removable plate to permit easy relamping. The luminous square (Fig. 90, II) is adaptable to high-class stores where the built-in type of lighting is desired but was not provided for when the ceiling was formed. The square mounts on the surface of the ceiling with an extension ring to fit over an

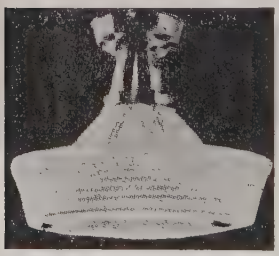


I (*a*). Suspension type.

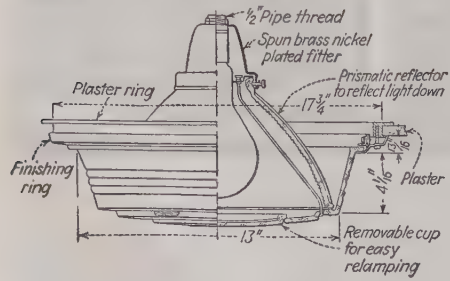




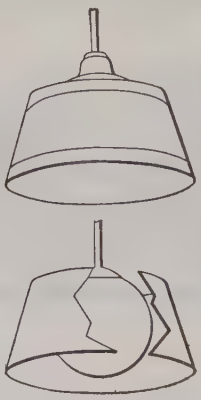
II. Luminous square. (*Holophane Co.*)



I (*b*). Surface-mounted type.



I (*c*). Sectional detail.



Cut-away view.

III. White globe with parchment shade. (*General Electric Co.*)

FIG. 90.—Semidirect luminaires for incandescent lamps.

existing outlet box to bring in the wiring. The bottom of the square consists of prismatic lenses above which are open-neck prismatic-glass reflectors. The sides of the square are enclosed with opal-glass panels. Most of the light is directed downward by the reflectors and lenses, but

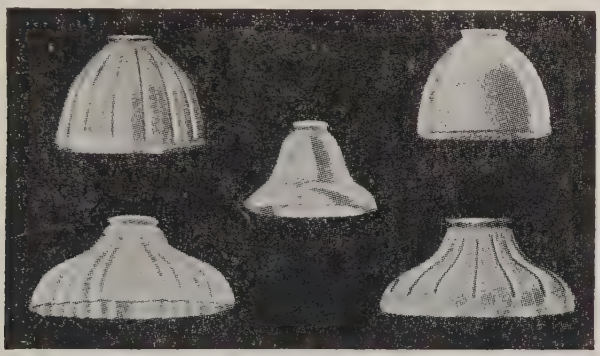


FIG. 91.—Types of open opal-glass reflectors. (*Miller Co.*)

a considerable portion escapes to the side panels and is diffused to the ceiling.

A method of using parchment shades over an opal-glass enclosing globe is illustrated in Fig. 90, III. The shades are white on the inside, and their conical shape directs a large part of the light downward, but as the shades are open at the top some light is permitted to reach the ceiling. This is an efficient method of providing a glarefree light for an office. It is more adaptable to improving an existing installation of opal-globe luminaires than for new installations, because the life of the parchment shades is limited, especially if the atmosphere is dirty. This type of luminaire is frequently employed in certain types of interiors for the artistic effect produced by the combination of the shades and globe.

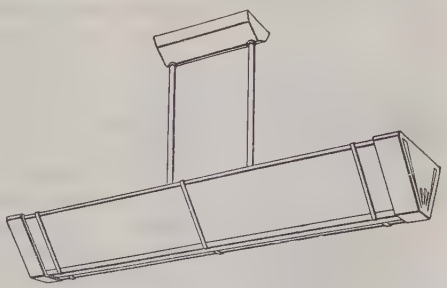
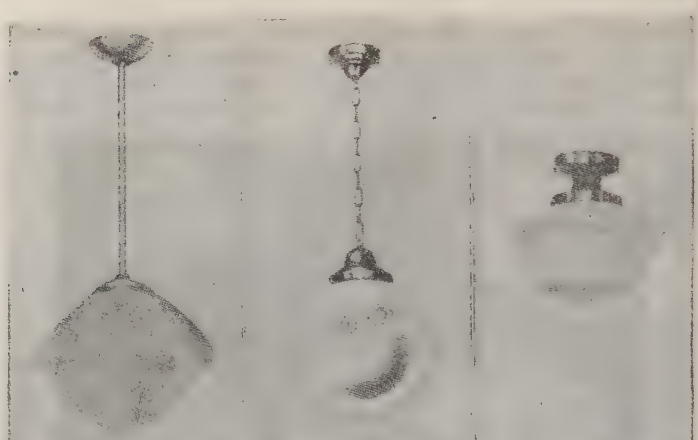


FIG. 92.—Semidirect luminaire for fluorescent lamps. (*Hygrade Sylvania Co.*)

Open-bottom types of opal-glass reflectors (Fig. 91) find a limited application in domestic use and as an economical means of providing localized lighting in out-of-the-way places where appearance is secondary.

165. A semidirect luminaire for fluorescent lamps is shown in Fig. 92. An Alzak aluminum reflector which is partially open at the top permits



I. Diamond shaped with stem suspension. II. Spherical globe with chain suspension. III. Trojan glassware with surface mounting.

FIG. 93.—General diffuse luminaires for incandescent lamps. (*Miller Co.*)

part of the light to reach the ceiling directly. The rest of the light is directed downward through a diffusing-glass panel. This luminaire is designed for commercial use where a good appearance with a fairly bright ceiling is more desired than low first cost.

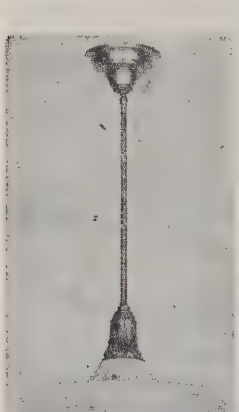
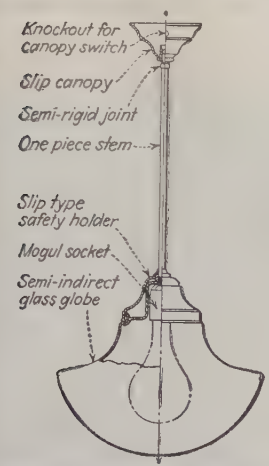


FIG. 94.—General diffuse luminaire with decorated glass globe. (*Westinghouse Electric & Manufacturing Co.*)

166. General diffuse luminaires are usually of the totally enclosing, opal-glass type (Fig. 93). The enclosing globes are made in a great variety of shapes with plain-glass finish as shown in Fig. 93 or with decorative designs as shown in Fig. 94. The globes diffuse the light well in all directions but have very little light-directing ability. The shape of the globe depends mostly on personal taste, so that it will harmonize with the surroundings. Any of the globes may be used with the stem suspension (Fig. 93, I), the chain suspension (Fig. 93, II), or the surface mounting (Fig. 93, III). The stem suspension presents a neat appearance, whereas the chain suspension has the advantage that the length of the suspension can be readily varied. Surface mounting is used mainly with low ceilings.

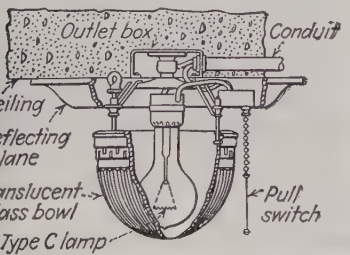
167. The great majority of semiindirect lighting units are constructed of opal glass. They may be of the completely enclosing or o

the open-top type. The globes of the completely enclosing type are constructed of two different grades of glass (Fig. 95, I). The top of the globe is made of either clear or light-density glass, while the lower portion is made of dense glass. This construction directs the greater portion of

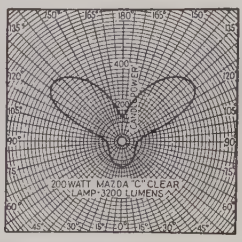


I. Opal glass enclosing globe. (*Westinghouse Electric & Manufacturing Co.*)

III. Prismatic glass. (*Holophane Co.*)



II. The "Brascolite." (Self-contained reflecting plane is provided in lieu of reflecting ceiling.) (*Edwin J. Guth Co.*)



IV. Characteristic curve.

FIG. 95.—Semiindirect luminaires for incandescent lamps.

the light to the ceiling, from which it is reflected back into the room. The open types (Figs. 95, II, and 96) are not so satisfactory because of the collection of dust inside the globe. The advantage of the one shown in Fig. 95, II, is that it provides its own reflecting plate so that it may be used on ceilings which are not good reflectors. The prismatic-glass type (Fig. 95, III) presents a more decorative appearance than the opal-glass

type. The prisms in the lower half of the unit are so molded that they redirect most of the downward light upward to the ceiling. A sufficient portion of the light is transmitted through the lower half of the globe to make the bowl luminous. A surface-mounted type of the same design is also available. An open semiindirect bowl made of plastic is shown in Fig. 96. It has about the same characteristics as the prismatic-glass one but is slightly cheaper and less efficient.

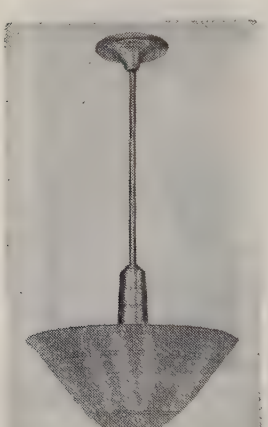


FIG. 96.—Plastic semiindirect luminaire for incandescent lamps. (*Miller Co.*)

FIG. 97.—Semiindirect luminaire for mercury Mazda lamps. (*Miller Co.*)

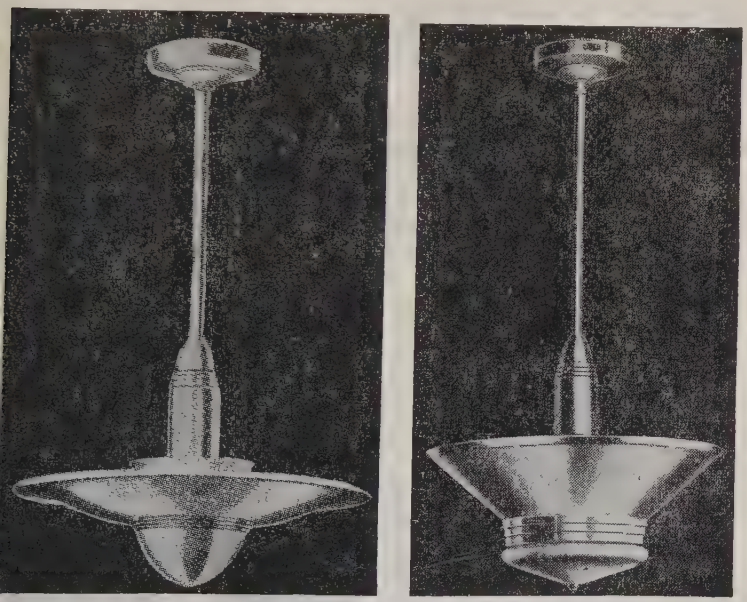
A type of aluminum and glass semiindirect luminaire for mercury Mazda lamps is shown in Fig. 97. The combination of polished aluminum rings, clear aluminum reflecting plates, and opal-glass plate presents a very decorative appearance for high-quality commercial use.

168. Luminaires for indirect lighting are made in many different styles to suit individual desires. Indirect lighting is coming to be the standard for commercial lighting on account of the well-diffused illumination which it provides, with absolutely no glare. Indirect luminaires are usually stem-supported for neatness of appearance. Some of the more common available types of indirect-lighting luminaires are described in the following paragraphs.

1. **Alzak aluminum luminaires for incandescent lamps** are shown in Fig. 98. An all-aluminum type is shown at I in the figure. It is a very efficient unit with the collar providing a very wide distribution characteristic. The dark appearance of the underside of the unit is not so

pleasing as the appearance of the luminous-bowl type shown at II. Enough light filters through the opal-glass bowl in this luminaire and is reflected up on the outside of the aluminum reflector to take away the dark appearance of the all-aluminum type.

2. **Enameled-steel indirect luminaires for incandescent lamps** are also made in the same types as shown in Fig. 98 with the outside finished in ochre with white bands. The appearance is somewhat better, but the cost is slightly higher than for the aluminum.



I. All aluminum. II. Luminous bowl.

FIG. 98.—Aluminum indirect luminaires for incandescent lamps. (*Edwin F. Guth Co.*)

3. **Glass indirect luminaires for incandescent lamps** (Fig. 99) are made n both surface-mounted and suspended types. The bottom of the glass owl may be either plain or decorated with bands or designs. The glass owls are generally open at the top. The glass is very dense, allowing nly a small portion of the light to be directed downward to provide a arm glow, but the brightness of the under surface is such that the unit lends with the ceiling and is very inconspicuous.

4. **Indirect luminaires employing mirrored-glass reflectors for use ith incandescent lamps** are shown in Figs. 100 and 101. Many differ- nt designs of shields to conceal the mirrored-glass reflector are available,

three of which are shown. The aluminum one shown at Fig. 100, I has the same disadvantage of dark outer appearance as discussed previously. The type shown at II has openings inside the turned-down edge which allow some rays of light to be reflected down the outside of the shield and relieve the dark appearance. By painting the inner surface of the turned-down edge, colored effects may be produced. This design is also made in the suspension type. The opal-glass shield shown in Fig. 101 provides a pleasing bright appearance.

5. **Two types of plastic indirect luminaires for incandescent lamps** are shown in Fig. 102. As shown by the characteristic curve at III a very small percentage of the light passes through the reflector and gives it a light appearance. Plastic reflectors are cheaper than the other types discussed but are slightly less efficient and may be distorted and deteriorated by the heat if large-sized lamps are used.

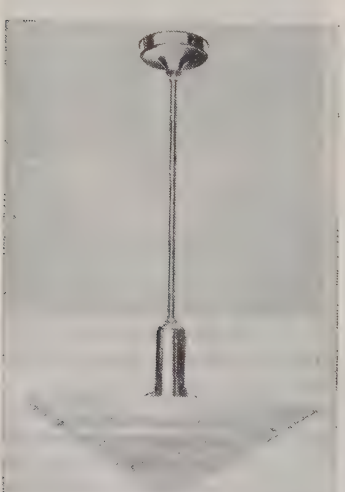
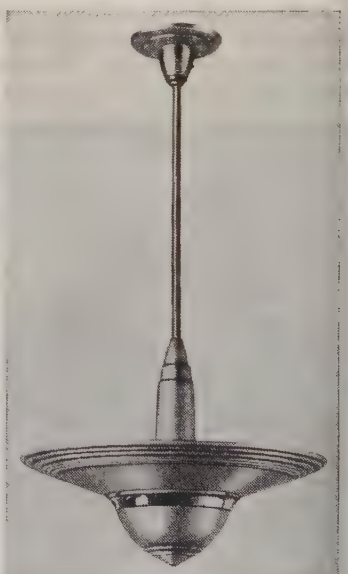
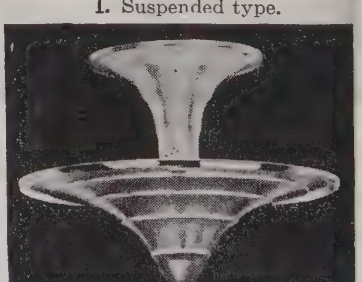


FIG. 99.—Suspended-type glass indirect luminaire for incandescent lamp. (*Westinghouse Electric & Manufacturing Co.*)



I. Suspended type.



II. Surface-mounted type.

FIG. 100.—Indirect luminaires with mirrored-glass reflectors and aluminum shields. (*Curtis Lighting, Inc.*)

6. **Indirect luminaires for silvered-bowl incandescent lamps,** similar in appearance to many of the designs discussed in the previous paragraphs, are available. Silvered-bowl lamps are more expensive than clear lamps, but the luminaires have a higher efficiency, and in many cases it can be proved that the cost of light per foot-candle is cheaper with silvered-bowl lamps than with clear lamps. A trough type of indirect luminaire for industrial use over inspection tables is shown in Fig. 103. This unit provides good local illumination with very little glare.

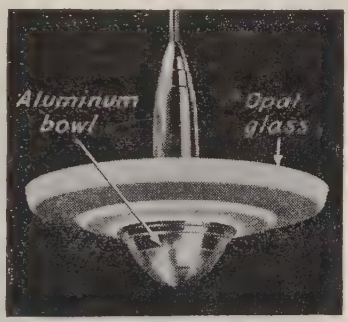
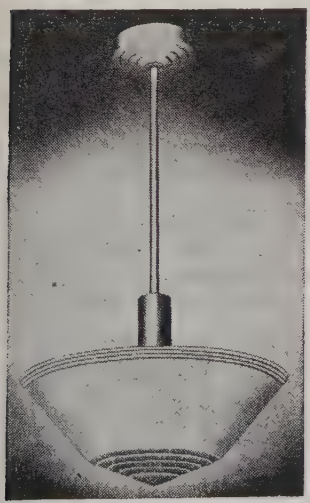


FIG. 101.—Opal-glass shield.

7. **Built-in luminaires** may be used in many ways to provide indirect lighting in connection with the interior architectural design of commercial buildings. The use of coves recessed in the wall a short distance from the ceiling is shown in Fig. 104, I. These coves employ a large



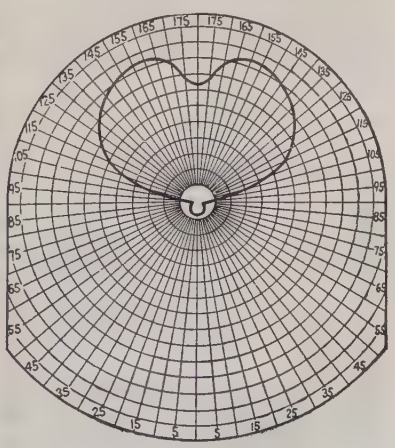


FIG. 102.—Plastic indirect luminaire for incandescent lamps. (*F. W. Wakefield Brass Co.*)

number of lamps of relatively small size and are especially useful in providing changing color effects by using several circuits and providing the lamps of each circuit with caps of a different color. Domes and ceiling recesses may be lighted as shown in Fig. 104, II. This method is

common for hallways or reception rooms. Wall urns as shown in Fig. 104. III are also used in reception rooms and sometimes in private offices. Coves on top of columns are common for high-ceiling public interiors. Where there are low partitions or bookcases, troughs may be mounted on top of them as shown in Fig. 104, IV, to provide concealed indirect lighting

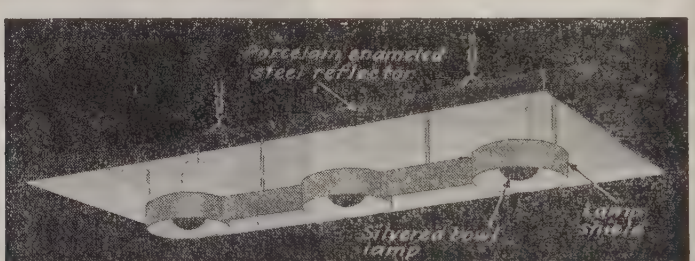


FIG. 103.—Indirect trough for silvered-bowl incandescent lamps. (*Edward J. Guth Co.*)

In general, built-in indirect lighting is less efficient than using the lumi naires described in the previous paragraphs because the less efficien small-sized lamps are used, and losses by multiple reflection are greater Their main field of application is for low illumination levels where the

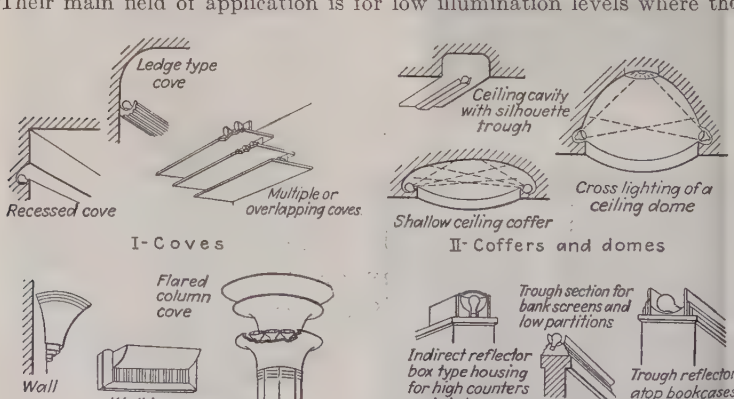


FIG. 104.—Types of built-in indirect luminaires for incandescent lamps

pleasing impression, created in the minds of those who use the buildings is of greater importance than efficiency and low operating cost.

8. **For indirect lighting with mercury Mazda lamps** the aluminum-glas unit of Fig. 105 is available. This is constructed similar to the one i Fig. 98, II, with two sockets, one for a 250- or a 400-watt mercury lam

and the other for a 300- or 500-watt incandescent lamp. The lamps are placed in an X formation and the light from the two is blended by cross reflection.

169. Selection of Luminaires.—The type of luminaire employed will affect (1) the amount of power required to produce a given illumination on the working plane, (2) the degree to which glare is eliminated, and (3) the character of the shadows produced. Unfortunately, there is no one type of equipment that will most satisfactorily meet all the conditions affecting the character of illumination. The types of luminaire which are the most effective with respect to the production of a given intensity and maintanance cost are not so effective in eliminating glare and reducing shadows.

The following rules are intended to serve as a general guide in the selection of luminaires.

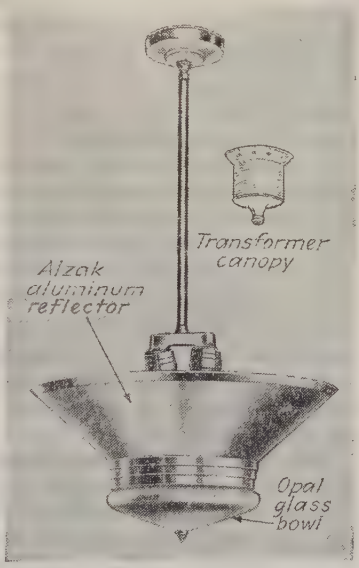


FIG. 105.—Indirect luminaire for combination mercury Mazda and incandescent lamps. (*Edwin F. Guth Co.*)

1. Direct-lighting equipment of the porcelain-enameled-steel and Alzak-aluminum-reflector types (Sec. **162,** (1) and (2)) are the most efficient with respect to the power required to produce a given intensity of illumination and are lowest in first cost. Although they do not eliminate shadows and guard against glare, they are perfectly satisfactory for the average industrial installation, when properly installed. Of these types the R.L.M. reflector is the most widely used for industrial work.

2. Direct-lighting equipment of the glassteel-diffuser and prismatic-glass and mirrored types (Sec. **162,** (3), (4) and (5)) are not quite so efficient with respect to the amount of power required for a given intensity of illumination and are more expensive, but they are considerably better in eliminating glare and shadows. The small portion of the light which is directed to the ceiling produces a better appearance of the lighted area and much more cheerful working conditions. These units are suitable for the better class of industrial installations and for some commercial applications where cost is of greater importance than appearance.

3. Semidirect- and general diffuse-lighting equipments (Secs. **164** to **166**) are not so efficient as the direct types but are much more efficient

than the semiindirect and indirect types, as far as power cost is co
cerned. Care should be exercised in selecting a particular unit of th
type to obtain one with a globe of sufficiently dense glass and of sufficie
diameter for the size of lamp employed so that the intrinsic brilliancy
the globe will not be so high as to cause discomfort or harm to the eye
Too low mounting and too wide spacing should be guarded agains
These lighting units are used considerably for commercial installatio
where the higher cost of the indirect lighting is not considered warrante

4. Semiindirect-lighting equipment (Sec. **167**) eliminates most of th
trouble with glare and shadows and provides a cheerful effect. Th
type is suitable for the better grade of commercial establishment whe
a slightly more efficient unit than the indirect type is desired.

5. Indirect-lighting equipment entirely eliminates glare and shadow
but is the most expensive as to power requirements and also, in mo
cases, as to first cost. This type is suitable for the highest quality
commercial installation where artistic effect, high-intensity illuminatio
and absence of glare are the important considerations. For the be
effect it is desirable to select a unit which is luminous on the bottom an
not totally dark.

170. The size of luminaire for incandescent lamps should be such th
the wattage rating of the lamp to be used with it will correspond to th
wattage rating of the luminaire. This is necessary for the proper di
tribution of light, for adequate dissipation of the heat produced by th
lamp, and for preventing excessive brightness of the unit. An exceptio
to this is that a smaller sized lamp may be used if an adapter is used i
the socket to bring the lamp bowl into the proper position in the luminai
When replacing lamps always use the same size as was used previousl
unless careful investigation is made as to whether a different size will b
satisfactory. With mercury-vapor and fluorescent lamps the design
such that only one size of lamp will fit a particular luminaire, and it
impossible to use the wrong size of lamp.

PRINCIPLES OF LIGHTING-INSTALLATION DESIGN

171. The general purpose of artificial lighting is to enable things to b
seen readily. Since things are seen by the light which is reflected fro
them (see Brightness, Sec. **39**) into the eye, it is necessary, in an effectiv
lighting installation, that the lighting units be of such number and s
arranged as to render most easily seen those things which it is desired t
see. To accomplish this, recognition must be made of the effect
light on the human eye.

172. Physiological Features of Artificial Lighting.—To appreciat
properly the principles of scientific lighting, it is necessary to understan
the mechanism of the eye. Figure 106 (from "Primer of Illumination,
copyright by Illuminating Engineering Society) shows the parts of th

eye as they would appear if it were cut through from back to front vertically. In the process of seeing, the light passes through the cornea, pupil, and lens of the eye to the retina, just as in a camera light passes through the lens to the sensitized film. The picture is formed on the retina, which is a layer made up of the ends of nerve fibers which gather into the optic nerve and go directly to the brain.

FIG. 106.—The eye—essential parts shown in section.

173. The optic nerve sends along the picture to the brain. The lens of the eye, unlike that of the camera, automatically changes in thickness to focus or make a clear image on the retina for seeing at different distances. This focusing action is called the accommodation of the eye, and when the light is dim or bad the focusing muscle vainly hunts for some focus which may make objects look clear and gets tired in trying to do it. The muscles which move the eye about also get tired in the same way, and the result is eyestrain, which stirs up pain and headache just as any other overtired muscles of the body may set up an ache.

FIG. 107.—Expansion and contraction of the pupil of the eye.

174. The iris (which gives the eye its color) serves to regulate the amount of light which reaches the eye. In very dim light it opens out making the pupil big, as shown in Fig. 107, and in very bright light it shuts up as shown and thus keeps out a flood of brilliant light which might hurt the retina. The protective action of the pupil is fairly good but by no means complete, for it seldom becomes smaller than shown in the illustration, however bright the light. From a study of Fig. 107 we may deduce:

1. When trying to see any object, do not allow a light to shine into the eyes, and do not face a brightly lighted area. In addition to tiring the retina, the superfluous light causes the pupil to contract, so that less light from the lighted object reaches the retina. An object which would seem well lighted in a room with dark walls, and with no light shining in the eyes, will appear poorly lighted in a bright room with light walls, or when a light is shining in the eyes, simply because the pupil is smaller. This also explains why a higher light intensity is necessary in the daytime than at night. It is generally easier to read with the same light source in a room having dark walls than if the walls are light in color—though the total illumination on the page will probably be less. Reflected light from glossy paper produces the same effect as light surroundings. The effect produced by a light shining directly into the eyes is termed *glare* (see Sec. **37**).

2. A fluctuating light causes the pupil to be constantly changing. This is very tiring to the muscles which control the iris, and if long continued may even work a permanent injury.

3. The lens of the eye is not corrected, as is a photographic lens, for color variations. It cannot focus sharply red and blue light from the same object simultaneously, although this is ordinarily not noticed. As white light is composed of all colors, it follows that we can see more clearly, *i.e.*, objects appear sharper and more distinct, by a monochromatic light (light of only one color) than even by daylight. The light from the mercury-vapor lamps closely approximates this condition.

4. Illumination should be uniform; otherwise the eye, in continually attempting to adapt itself to the unequal conditions, becomes tired in the same way as with a fluctuating light.

Correct lighting enables one to see clearly with minimum tiring of the eyes. To secure this, all the above conditions must be satisfied.

175. The requirements of a satisfactory lighting installation (Ward Harrison, "Electric Lighting") are: (1) Sufficient light of unvarying intensity on all principal surfaces, whether horizontal, vertical, or oblique planes. (2) A comparable intensity of light on adjacent areas and on the walls. (3) Light of a color and spectral character suited to the purpose for which it is employed. (4) Freedom from glare and from glaring reflections. (5) Light so directed and diffused as to prevent objectionable shadows or contrasts of intensity. (6) A lighting effect appropriate for the location and lighting units which are in harmony with their surroundings, whether lighted or unlighted. (7) A system which is simple, reliable, easy of maintenance, and in initial and operating cost not out of proportion to the results attained. The neglect of any one of these requirements may result in an unsatisfactory installation.

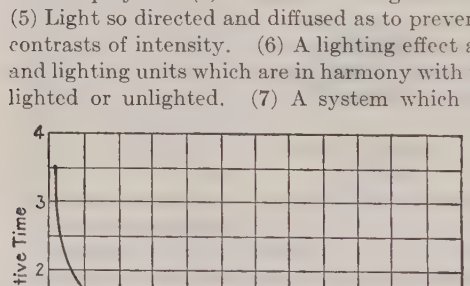


FIG. 108.—Effect of intensity of illumination upon time required for perception. (*General Electric Co., Nela Park Engineering Department.*)

176. Intensity of Illumination.—Although the eye is capable of adjusting itself to perceive objects over a wide range of intensities, the speed of this perception and the ability to distinguish fineness of detail is improved as the intensity increases, until the intensity becomes so great that a blinding effect is produced. An intensity of illumination that will be so high as to produce a blinding effect is, however, far above the range of intensities utilized in artificial illumination. The effect of the intensity of illumination upon the length of time required for the perception of objects is shown in Fig. 108. The effect

of the intensity of illumination upon the length of time required for the discrimination of detail is shown in Fig. 109. From a study of the curve of Fig. 108 it is seen that the speed of perception increases approximately proportionally to the intensity of illumination, until an illumination of 5 ft.-c. is reached. Above this point the increase in speed of perception for a given increase in intensity gradually decreases. From these facts a few years ago it was erroneously considered that intensities of illumination above 5 ft.-c. were of little practical value in making things more clearly seen. That this is not true has been definitely proved not only by laboratory tests but also by practical tests in actual working areas. High levels of illumination have been found to result in an actual saving in dollars and cents owing to the increased production and decrease in spoilage produced by their use. Recommended values of intensities are given in Tables 200 and 201.

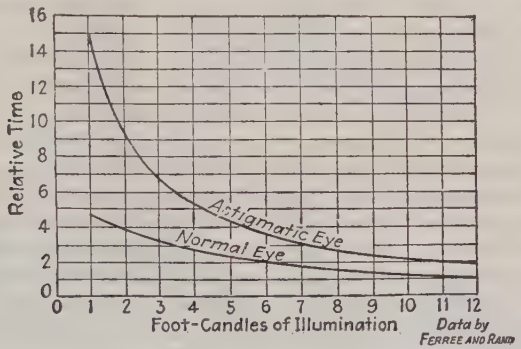


Fig. 109.—Effect of intensity of illumination upon time required for discrimination of detail. (*General Electric Co., Nela Park Engineering Department.*)

177. Blink Test.—In order to have some definite and scientific way of measuring eyestrain and fatigue, the General Electric Co. devised the "blink" test. In this test the number of blinks per minute which the eye makes involuntarily are counted. This is done when the eyes are in a rested condition and then again after an hour of work at the various usual tasks of the individual under different levels of illumination. The rate of increase in blinking is taken as a measure of eye and nerve fatigue. The rate of blinking always increases some with working or reading, but the higher the illumination intensity, up to at least 75 or 100 ft.-c., the lower is the rate of blinking, especially where attention to fine detail is required. The results of these tests have been considered in making up the values for Tables 200 and 201.

178. Elimination of Glare.—The greatest care should be exercised in designing a lighting installation to avoid the presence of any one of the three types of glare described in Sec. **37.** In order that a lighting unit

which is in the central portion of the visual field will not produce glare its brightness should not exceed from 2 to 3 candles per sq. in. of apparen area. If the eyes are not to be fatigued, when the unit is viewed con tinually, the brightness should not exceed ½ candle per square inch o apparent area. The maximum permissible brightness is, of course influenced by the darkness of the surroundings.

No less important than the elimination of direct glare is the avoidance of reflected glare or specular reflection. Its effects are often more harm ful than those due to direct glare. The use of highly polished furniture plate-glass desk tops, and glossy finishes on walls should be avoided. A large expanse of too light-finished wall surface will be a cause of harmfu glare in offices, schoolrooms, and other locations where the occupants o the room must sit facing the wall for long periods of time. Although i is always desirable to have walls finished in light colors such as cream o buff in order to utilize as effectively as possible the light emitted by the source, the reflection factor of the lower walls should not be so high as t cause eye fatigue to the occupants. For rooms where the occupants mus face the walls for long periods of time, the reflection factor of the part o the wall below eye level should not be greater than 50 per cent.

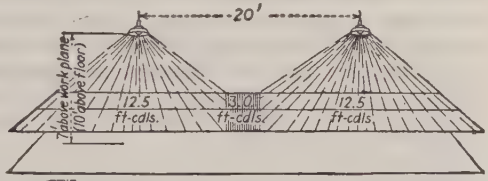
179. Production of Shadows.—The character of the shadow cast by an object depends upon the uniformity of the illumination in the area and upon the direction of the light falling upon the object. If the ligh falling upon an object is coming from one direction only, a sharp dens shadow will be cast. As the number of the directions in which light i impinging upon an object is increased, the sharpness and denseness o the shadow cast will be reduced. A shadow will still be cast even if th object is illuminated from all directions, unless the intensity of the illumi nation is the same in all directions. In order, therefore, completely t eliminate shadows, the illumination must be uniform and completely diffused, *i.e.*, so the illumination of any point will be produced by ligh from all directions. The less uniform the illumination is or the fewer th directions of light falling upon an object, the more dense and sharp wi be the shadows cast.

The desirability of shadows in an illuminated area depends upon th nature of the installation. In no installation is it desirable to have com plete uniformity of illumination, *i.e.*, illumination with no shadows o contrast in the intensity of illumination. Such illumination woul produce a cold and flat effect that would be tiresome to the eye. Neithe could the shape and contour of objects be discerned. On the other hand it is equally bad to have illumination which results in very dark, dens shadows and excessive contrasts in the intensity of illumination of diffe ent areas. Such illumination would be very hard on the eyes, owing t the continual change in the size of the retina as the field of vision is varied When shadows are too dark an object cannot be distinguished from it

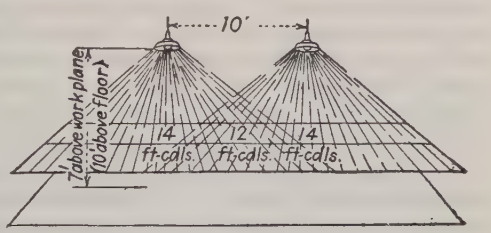
shadow, the shape of the object is not clearly seen, and objects in the shadows are not discernible. These conditions are frequent causes of accidents in poorly illuminated areas.

Shadows of the proper quality are of great value in observing objects in their three dimensions, in determining the shape of an object, and in determining irregularities in surfaces. They are of no value in the observation of plane surfaces. Shadows should never be dark and dense. Where shadows are essential, they should be soft and luminous so that the object is clearly discernible from its shadow, and so that there is no great marked contrast in intensity of illumination.

180. Uniformity of illumination is usually expressed as a maximum deviation from the average or mean intensity of illumination. It is not necessary to have the illumination of an area exactly uniform in order that the contrasts in the illumination of different portions will be unobservable by the eye or so that the shadows will be too dense or sharp. The degree of uniformity of illumination obtained depends upon the ratio of the spacing distance of the lighting units to their mounting heights. For any reflector there is a maximum spacing of the units for a given mounting height that should not be exceeded if satisfactory uniformity of illumination is to be obtained. The effect of the spacing of the units upon the uniformity of illumination is illustrated in Fig. 110. Although this maximum spacing distance varies somewhat for reflectors giving different distribution of the light emitted by them it is a good general rule to make the spacing distance equal to the mounting height. A greater spacing distance is likely to result in sharp and too dense shadows. One need not hesitate to use a closer spacing distance than that equal to the mounting height if desired, since the closer the spacing the more uniform will be the illumination of the area. For the average



I.—Nonuniform illumination, too great spacing between units. (Foot-candle values based on 200-watt units.)



II.—Uniform illumination, proper spacing of units. (Foot-candle values based on 200-watt units.

Fig. 110.—Effect of spacing of outlets on uniformity of illumination.

installation it is best to keep the spacing distance of the units within th values of Table 195. Where the ceiling is exceptionally high, closer spac ing distances than these may be advisable in order to reduce the densit of the shadows. In the illumination of certain areas such as storag spaces, it is permissible to space the units slightly farther apart.

181. Methods of Illumination.—With respect to the arrangement o the light sources the methods of illumination may be divided into fou classes as follows:

1. Localized.
2. General.
3. Group or localized general.
4. Combination of general and localized.

In the **localized method** an individual lighting unit of small wattag is supplied for each worker, machine, or workbench; the units are sup ported at a low level so as to bring the light close to the work. Ther is no attempt to produce uniform illumination over the total area.

With the **general illumination method** the lighting units are supporte fairly close to the ceiling or at least a considerable distance above th working plane. They are spaced uniformly throughout the area withou special regard to the location of machinery, furniture, etc., and at such distance from each other as to give nearly uniform illumination.

The **group method** is somewhat of a compromise between the localize and general methods. The lighting units are mounted close to the ceilin or at a considerable distance above the working plane. The units ar not spaced uniformly but are located with respect to the machinery position of operators, etc., so as to give sufficient illumination for wor at each machine. The illumination of the area is not uniform.

In the **combination of general and localized methods** uniform illumina tion is supplied over the complete area by means of units located accord ing to the general method. This illumination is supplemented with loca lights for certain operations that require a higher intensity than tha required for the main area.

182. Comparison of Methods of Illumination.—The localized arrange ment of lighting units in industrial and most commercial application should be a thing of the past and should never be tolerated. It produce very dense shadows and such low intensities in the general area that it i likely to be the cause of very serious accidents. Such a method wi prove to be very harmful to the occupants of the room, owing to direc glare from the low-hung lamps and may so blind the operators of machine that they will be severely injured.

For the great majority of installations the general method of arrangin the light sources is the most satisfactory. It is the method most com monly employed. For some classes of work which require a very hig intensity of illumination at the working point it would not be economica to light the whole area to this high intensity. These conditions can b

satisfactorily met by means of the combination of the general and localized methods, provided the local lamps are well shielded to prevent the possibility of glare. With the combination method the ratio of local to general illumination intensity should not be greater than 10:1. In other words, if some operations require 75 ft.-c. the general illumination should be not less than 7½ ft.-c.

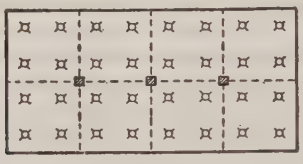
In some places where there are machines with large overhanging parts, and in rooms with high obstructions, the group method will direct the light upon the working parts better than the general arrangement. The group method is frequently a good arrangement for rooms containing a number of similar machines arranged in rows.

183. Effect of Proportions of Room.—Of the light which strikes the walls of a room only part is reflected back into the room to become useful upon the working plane. Consequently, the greater the proportion of the total light that is directed to the walls, the lower is the intensity of illumination on the working plane; or, stated in another way, the greater the proportion of the total light that is directed to the walls, the larger must the lamps be to produce a given intensity on the working plane. The proportion of the light that strikes the walls depends upon the size of the room and the height at which the units are mounted. In a large room the ratio between the wall area and the floor area is less than for a small room. Thus, for the same mounting height a smaller proportion of the total light will strike the walls than in a small room. In large rooms, therefore, less light is absorbed by the walls than in small rooms.

In a room of given dimensions, if the mounting height of the units is increased, more light will fall upon the walls. One should be careful not to get the impression that it is best to mount the units as low as possible. Although less light is absorbed by the walls with low-hung units, there are other more important factors that are affected by the mounting height. As the mounting height of the units is reduced, the spacing between them must also be reduced in order to produce uniform illumination and so that the shadows will not be too dense. The cost of installing a large number of small units is greater than that of installing a smaller number of larger units. Also, the larger-sized lamps are much more efficient with respect to the number of lumens produced per watt. As a result, the saving from the use of large units mounted high more than offsets the increased absorption of light by the walls. For practically all installations it is best to mount the units as high as possible. There is less probability of glare with high-mounted units than with low-hung ones, since the units are not so likely to be in the field of view.

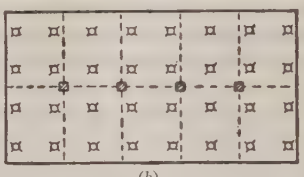
Table 197 classifies room proportions, dependent upon their effect upon the useful illumination, into 10 classes as indicated by letters *A* to *J*. This serves as a reference index for use with Table 199 in determining the coefficient of utilization.

184. Effect of Character of Finish of Walls.—Of the light that falls upon the walls or ceiling of a room the percentage that is reflected back into the room depends upon the color of the wall and ceilings and the type of paint employed. The lighter the color, the greater will be the



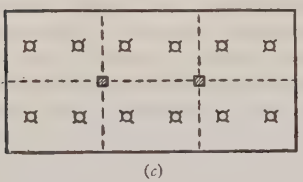
(*a*)

Four Units per Bay.—This is the most common system for the square bay of usual dimensions.



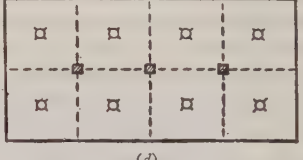
(*b*)

Four-two System.—This is equivalent to three units per bay and is an alternative to four per bay where spacing allows.



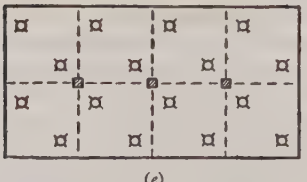
(*c*)

Two Units per Bay.—Usually applicable only in narrow bays where the width is less than two-thirds the length.



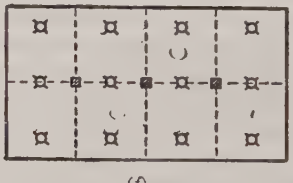
(*d*)

One Unit per Bay.—A very common practice, but satisfactory only where bay size is no greater than the maximum permissible spacing—an unusual condition.



(*e*)

Staggered System.—A recourse where one unit per bay is unsatisfactory and where four per bay is unnecessary. Less favorable appearance, and certain areas near walls may be inadequately lighted. Often expensive to wire.



(*f*)

Interspaced System.—Applicable in rectangular bays where one unit per bay would exceed the permissible spacing in one direction, and where center row will not interfere with future structural arrangements, such as added office partitions.

FIG. 111.—Layouts of lighting units for symmetrical spacing. (*General Electric Co., Nela Park Engineering Department.*)

coefficient of reflection. The reflection factor of two freshly painted walls of practically the same color may differ, however, by several per cent depending upon the grade of paint employed. The reflection factor of a surface decreases as time elapses after the painting. The amount of this depreciation in reflecting power varies widely with different grades o

paint. It is important to have the walls and ceiling light in color and to employ a good grade of paint which will have a high initial reflection factor that does not depreciate an excessive amount with age. The walls, however, should not be made so bright as to be a source of glare (See Sec. **178**).

185. Location of Lighting Equipment.—The lighting units for general illumination should be located symmetrically throughout the area to be illuminated. When the room is divided into bays by means of columns, roof trusses, or girders, or when the ceiling is divided into panels, the units should be arranged symmetrically, for the sake of appearance, with respect to such architectural divisions, provided it will not interfere with the uniformity of illumination. Typical layouts of lighting units are given in Fig. 111. In order to obtain uniformity of illumination (see

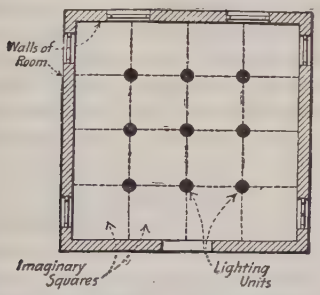


Fig. 112.—Wrong arrangement of lighting units.

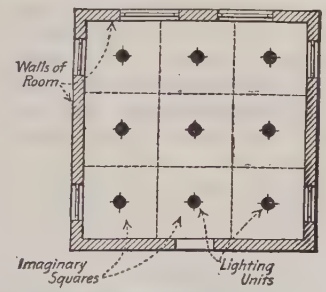


Fig. 113.—Correct arrangement of lighting units.

Sec. **180**) a layout should be chosen which will provide a spacing between units no greater than that given in Table 195.

Where the number and location of lighting outlets are not automatically determined by architectural considerations or by the arrangement of the furniture and fixtures, it is desirable to arrange the lighting outlets in the form of squares or rectangles. It is important that the units be placed at the centers of the squares and not at the corners. Figure 112 shows a method of locating outlets which is undesirable because it gives a very low intensity of illumination near the walls compared with that at the center of the room. Figure 113 shows the correct method of locating outlets in the centers of the squares. In certain cases, notably in office lighting and in rooms with benches located along the walls, it may, to minimize shadows, be desirable to place the outer rows of outlets somewhat nearer the side walls of the room than they would be if symmetrically arranged as shown in Fig. 113.

In laying out a lighting installation the maximum permissible spacing distance for the production of uniform illumination and satisfactory density of shadows should be determined first. Then locate the units

on a plan of the area so as to be located symmetrically with respect architectural conditions, and at the same time not to exceed the maximu permissible spacing distance.

When the outlets are located above traveling cranes, the stagger system (Fig. 111*e*) is preferable so that, as the crane moves along, it cu off the light from only one unit at a time. If it is not desired to use t staggered system, additional lighting outlets, with special shock-abso ing sockets, should be located on the underside of the crane truss so th as the crane moves along, the light from those units replaces the lig from the regular outlets which are cut off by the crane.

In buildings of mill-type construction the units are usually support on the lower chord of the roof truss or suspended from the roof purli When the units are mounted on the lower chord of the roof truss, the illu nation near the walls at each end of the building is low. When wo must be carried on in these areas, it is better to support the units from t purlins or to locate a row of angle units along each end wall.

High mounting is desirable because then the lamps are out of the w of cranes and are less apt to be broken, the glare is reduced to a minimu and in the case of a light ceiling there is more reflection and better d fusion of light. The lamps should be lowered in locations where there horizontal overhead belting, to the level of the bottom of the belti otherwise a portion of the light is ineffective. It may be necessary, the same reason, to install two or three units in an area where the co ditions would otherwise warrant only one unit.

186. Maintenance of Lighting Equipment.—The intensity of illumi tion produced by a lighting installation will be somewhat less, after t system has been in use for some time, than the intensity was when t system was first installed. This depreciation in the lighting system due to the decrease in efficiency of the filament of the lamp with use, a to the decrease in reflecting efficiency of the reflecting equipment, wa and ceiling, which is the result of the natural deterioration of the surfa with age, and of the collection of dust and dirt.

In the design of lighting installations, a maintenance factor is used take into account this depreciation. It has values less than unity so th when the initial illumination is multiplied by the maintenance factor, t actual illumination after a period of several months' use will be obtain

The amount of depreciation will vary from 25 to 45 per cent, corresp ing to a maintenance factor of 0.75 to 0.55, depending upon the type a material of the reflecting equipment, the system of illumination employ the local conditions of dust and dirt, and the frequency of cleaning equipment and repainting of walls. See Table 199 for values for maintenance factor. All lighting units should be adequately cleaned regular intervals (about every 2 to 6 weeks), in order to prevent a waste energy and low intensity of illumination. The frequency for the clean

periods depends upon the degree of prevalence of dust and dirt and upon the type of luminaire.

187. The coefficient of utilization is the over-all efficiency of the lighting installation: the ratio of the useful lumens which get down to the working plane to the total lumens generated by the lamp. Table 199 gives values for the coefficient of utilization for different types of luminaires, subdivided according to room index and reflection factors for walls and for the ceiling.

188. Reflection factor is the percentage of light reflected from a surface, such as a wall or ceiling, to the total light falling on the surface. The difference between the reflection factor and 100 per cent represents the percentage of light which is absorbed by the surface and lost. Reflection factors for some of the common colors are given in Table 198. The reflection factor varies with the roughness of the surface as well as with the darkness of the color. For a more complete color chart see General Electric bulletin LS-341.

189. There are two principal methods used in calculating illumination:

1. Point-by-point method.
2. Lumen method.

190. The point-by-point method is based on the inverse-square law that the intensity of light flux varies inversely as the square of the distance from the light source to the point of measurement (see Sec. **25** and Fig. 114). The illumination on any plane perpendicular to the light rays is given by the following formula:

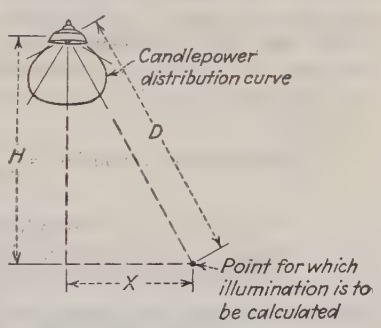


Fig. 114.—Point-by-point method of lighting calculations.

$$\text{Foot-candles (on perpendicular plane)} = \frac{\text{c.p.}}{D^2} \qquad (7)$$

where c.p. = the candle power of the light source in the direction in which the distance D is taken; and D = the perpendicular distance from the light source to the illuminated plane in feet.

Since the illumination on the horizontal plane is the value usually desired, the formula must be multiplied by the ratio H/D (see Fig. 114) or

$$\text{Foot-candles (on horizontal plane)} = \frac{\text{c.p.} \times H}{D^3} \qquad (8)$$

If the illumination on a vertical plane is desired, the basic formula (7) must be multiplied by the ratio X/D (see Fig. 114) or

$$\text{Foot-candles (on vertical plane)} = \frac{\text{c.p.} \times X}{D^3} \quad (8.$$

The illumination at any point is obtained by adding the foot-candl due to each light source which is sending rays of light to the point.

It is obvious that the point-by-point method is practical for use on with the direct type of lighting, for with any other system of illuminati the number of light sources which would have to be considered wou make the calculations prohibitively tedious. Even with the dire system it is usually necessary to calculate the foot-candles from sever different light sources. This method is especially applicable to cal lating localized lighting where only a single light source needs to considered.

191. In the lumen method of calculating illumination, the lume required of the light source are calculated from the useful lumens desir on the working plane. In doing this, a maintenance factor, as explain in Sec. **186,** and an efficiency factor, called a coefficient of utilizati (Sec. **187**), take account of the lumens absorbed in the luminaire and the ceiling and the walls. With this method the following formulas m be used:

$$\text{Lamp lumens per outlet} = \frac{\text{foot-candles} \times \text{area per outlet}}{\text{coefficient of utilization} \times \text{maintenance factor}}$$

$$\text{Foot-candles} = \frac{\text{lamp lumens} \times \text{coefficient of utilization} \times \text{maintenance factor}}{\text{area per outlet}} \quad (1$$

This method gives the average illumination on the horizontal for a system of general illumination where the light sources are spaced su ficiently close together to give approximately uniform illumination.

192. The necessary successive steps in designing the average inter general-lighting installation by the lumen method are:

1. Consider carefully a floor plan of the area and all the general facto which affect the problem, such as type of work to be carried on; location furniture, machines, etc; character of architecture; finish of walls a ceiling; and structural details of building.

2. Select method of arranging light sources: general, group, or co bination of general and localized (refer to Secs. **181** and **182**).

3. Select the most applicable system: direct, semidirect, general d fuse, semiindirect, or indirect (refer to Secs. **146** and **150**).

4. Select the type of electric illuminant which should be used: inca descent, fluorescent, mercury vapor, mercury Mazda, or combinati mercury Mazda and incandescent (refer to Secs. **91, 92, 104, 117, 1** and **120**).

5. Select the type of luminaire which should be employed (refer Sec. **169**).

6. Locate the lighting units on a floor plan of the area as required by the structural conditions (See Sec. **185**). In doing this, be careful not to exceed the maximum permissible spacing distance as given in Table 195 (refers to Figs. 111 to 113).

7. Determine the exact mounting height from a study of the structural conditions (Sec. **185**) and Table 196. It is usually desirable to mount the units as high as possible up to 12 ft. If the units are mounted higher than this, special arrangements should be made for cleaning.

8. Determine the room index from the dimensions of the room and the height of the reflecting equipment (refer to Table 197).

9. Determine the reflection factor of the walls and of the ceiling (refer to Table 198).

10. Determine the maintenance factor and the coefficient of utilization interpolating for wall and ceiling reflection factors, if necessary (refer to Table 199).

11. Select the intensity of illumination in foot-candles which should be employed (refer to Table 200 or 201).

12. Compute:

$$\text{Area per outlet} = \frac{\text{floor area of the room or part of room}}{\text{number of outlets in the room or part of room}}$$

13. Solve For. (9) of Sec. **191.**

14. Select from Table 80 the size of lamp to use, according to the lumens required. If the required lumens fall midway between two lamp sizes, both the size above and the size below will have to be considered as outlined in 15 and 16 below.

15. Solve for each size of lamp, For. (10) of Sec. **191.**

16. Refer to step 11 and decide whether the foot-candles obtainable with the smaller lamp will be sufficient. For incandescent lamps consider the possibility of using lamps of a voltage rating 5 volts less than the circuit voltage, as explained in Sec. **84.** In case neither of these possibilities is satisfactory, the larger size of lamp should be used, or a different spacing of units and a complete recalculation may be tried to see if an installation closer to an actual size of lamp may be obtained.

Example.—Suppose a dry-goods store (Fig. 115) is to be lighted, the dimensions of which are: length, 72 ft.; width, 24 ft ; height, 15 ft. The ceiling is light and the walls are dark. What should be the illumination design?

Solution.—The floor plan (Fig. 115) shows no bays, posts, or other obstructions to be considered. Soft shadows, good vertical illumination for wall-cases, minimum glare, and good decorative effect are the requirements which, for this class of service, the lighting should satisfy. Either general-diffuse or indirect illumination (Secs. **148** and **150**), may be employed. The choice between these two systems would depend upon the character of the store. If the store were a general dry-goods store in a small city, the general-diffuse system would undoubtedly be selected because of its high efficiency. On the other hand, if the store were a high-grade establishment, the indirect system would be preferred.

The general illumination method (Secs. **181** and **182**) should be used. Refer to Sec. **169** for a guide to the selection of the lighting equipment. The choice of lighting equipment will be between the general-diffuse and the indirect luminaires. Whether a general-diffuse or indirect luminaire is selected will depend upon the system of illumination selected above, governed by the character of the store. The design of the installation for both cases is given below.

Design Employing General-diffuse Lighting.—Assume that one of the white enclosing globe luminaires of Figs. 93 or 94 is selected.

The mounting height will be 13 ft., determined by subtracting 2 ft. from a ceiling height of 15 ft. From Table 195 a spacing of 10 to 12 ft. between units is permissible for a mounting height of 13 ft.

From Table 197 for a room 24 ft. wide and 72 ft. long and with a mounting height of 13 ft. the room index is *F*. From Table 198 the reflection

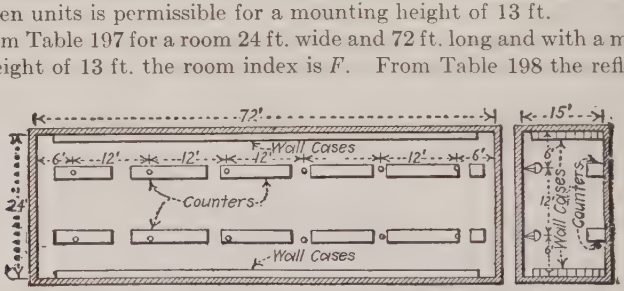


FIG. 115.—Illustrating method of calculating illumination.

factor for a light ceiling should be about 70 per cent and for a dark wall about 30 per cent.

Referring to Table 199 the maintenance factor for a general-diffusion fixture (No. 11 in Table 199) is 0.75, and the coefficient of utilization for 70 per cent ceiling with a 30 per cent wall is about 0.35 (interpolated between 0.36 for a 75 per cent ceiling and 0.32 for a 50 per cent ceiling).

From a study of the plan of the store (Fig. 115) the obvious solution is to divide the room into twelve 12-ft. squares and suspend a unit at the center of each square. Since this spacing is equal to the maximum allowable spacing, such a layout of units will be satisfactory.

From Table 201 an intensity of illumination of from 15 to 20 ft.-c. should be employed.

$$\text{Area per outlet} = \frac{24 \times 72}{12} = 144 \text{ sq. ft.}$$

$$\text{Lamp lumens per outlet [For. (9), Sec. 191]} = \frac{15 \times 144}{0.35 \times 0.75} = 8{,}230 \text{ lumens}$$

Referring to Table 80, the choice is between a 300-watt clear lamp giving 5,750 lumens and a 500-watt clear lamp giving 10,000 lumens. Since the 5,750 lumens is so far below the desired 8,230, the 500-watt 10,000-lumen lamp should be used.

$$\text{Actual foot-candles [For. (10), Sec. 191]} = \frac{10{,}000 \times 0.35 \times 0.75}{144}$$

$$= 18.3 \text{ ft.-c.}$$

Since 18.3 is between the 15 and 20 ft.-c. desired the installation is satisfactory.

Design Employing Indirect Lighting.—Assume that one of the luminaires of Fig. 101 is selected. Use the same spacing of 12 ft. as determined in the previous design.

From Table 197 for a room 24 ft. wide and 72 ft long, with a ceiling height for indirect lighting of 15 ft., the room index is *E*.

Referring to Table 199 for a No. 14 fixture, the maintenance factor is 0.65, and the coefficient of utilization for a 70 per cent ceiling with a 30 per cent wall is 0.25 (interpolated between 0.27 for a 75 per cent ceiling and 0.18 for a 50 per cent ceiling).

$$\text{Area per outlet} = \frac{24 \times 72}{12} = 144 \text{ sq. ft.}$$

$$\text{Lamp lumens per outlet [For. (9), Sec. 191]} = \frac{20 \times 144}{0.25 \times 0.65}$$

$$= 17{,}700 \text{ lumens}$$

Referring to Table 81 the choice is between a 750-watt clear lamp giving 14,500 lumens and a 1,000-watt clear lamp giving 21,000 lumens.

For the 750-watt lamp:

$$\text{Actual foot-candles [For. (10), Sec. 191]} = \frac{14{,}500 \times 0.25 \times 0.65}{144}$$

$$= 16.4 \text{ ft.-c.}$$

For the 1,000-watt lamp:

$$\text{Actual foot-candles [For. (10), Sec. 191]} = \frac{21{,}000 \times 0.25 \times 0.65}{144}$$

$$= 23.7 \text{ ft.-c.}$$

Since the 16.4 ft.-c. is within the range of 15 to 20 desired, the 750-watt lamp is the one to use.

Referring to a manufacturer's price list we find that the 750-watt lamp costs about three times as much as the 500-watt size. Consideration should, therefore, be given to using more luminaires with 500-watt lamps spaced closer together.

A spacing of 9 ft. between units along the length of the store would give:

$$\text{Area per outlet} = \frac{24 \times 72}{16} = 108 \text{ sq. ft.}$$

For the 500-watt lamp:

$$\text{Actual foot-candles [For. (10), Sec. 191]} = \frac{10{,}000 \times 0.25 \times 0.65}{108}$$

$$= 15.0 \text{ ft.-c.}$$

Since this value is the minimum of 15 ft.-c., consideration should b given to burning these lamps at 5 volts overvoltage.

Referring to Sec. **84** and using the same assumptions as in the sampl problem there, the illumination would be 116 per cent of 15.0 = 17.4 ft.-c Assume 20 per cent discount from list price for lamps.

Comparison of Annual Cost at Energy Charge of 1 Ct. per Kw.-hr. an Demand Charge of $1.50 per Kw.

Item	Using 12 750-watt lamps at rated voltage	Using 16 500-watt lamps at 104 per cent of rated voltage
Annual cost of lamps...	$1\frac{1}{2} \times 12 \times \$2.60 = \$ 46.80$	$2\frac{1}{2} \times 16 \times \$0.88 = \$ 35.0$
Cost of energy for 1,500 hr.....	$12 \times \frac{750}{1,000} \times 1,500 \times \$0.01 = \$135.00$	$16 \times \frac{500}{1,000} \times 1.085 \times 1,500 \times \$0.0$ $= \$130.0$
Demand charge for 12 months.....	$9 \text{ kw.} \times \$1.50 \times 12 = \$162.00$	$8.68 \times \$1.50 \times 12 = \$156.6$
Total.....	\$343.80	\$321.6

This indicates an annual saving of $23 in favor of the smaller lam burned at overvoltage. The initial cost would also be less (approx mately $9 for one fixture and lamp or $144 for the 16, compared wit $14.50 each or $174 for the 12).

Since the 500-watt lamps would furnish about 1 ft.-c. more illuminatio at about $25 per year less cost, the installation of 16 500-watt lam should be recommended.

192A. In designing a general lighting system with fluorescent lam proceed as in Sec. **192** except use Table 199A for maintenance factors an coefficients of utilization. Fluorescent lamps cannot be operated at ove voltage as was suggested for incandescent lamps.

193. In designing a general lighting system with mercury Mazd lamps or a combination mercury and incandescent system proceed follows:

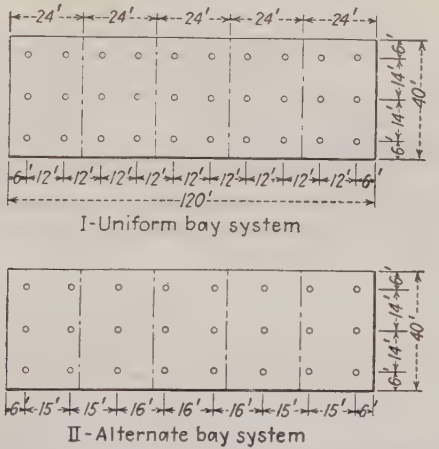
1. Decide whether the installation is to be straight mercury, alterna incandescent and mercury, or combination luminaires (refer to Secs. **1** and **118**).

2. Proceed as in Sec. **192.** For the alternate system calculate ea system separately, allowing about one-half of the total illumination to obtained from each source. The total illumination will be the sum of t two. For combination luminaires make one calculation and divide t required lumens so as to select one of the combinations listed from Se **118** (3) and use from Table 111 either the 250-watt A-H2, the 400-wa A-H1, or the 3,000-watt A-H9 lamp.

3. Respace the lighting units in case the desired combination of lamps s not obtainable. This may be necessary since there are only three sizes f mercury lamps for general lighting.

Example.—Determine the number, spacing, and size of lamps for a combination mer- ury and incandescent system to illuminate a machine shop 40 by 120 ft. to an average ntensity of 20 ft.-c. The roof is sloping and supported on trusses with the bottom of he truss 15 ft. above the floor.

Solution.—The fixtures will be hung from the roof with the bottom of the fixture even ith the bottom of the roof trusses. From Table 195 a height of 15 ft. requires a spacing



IG. 116.—Layout of combination mercury and incandescent lamps for a machine shop.

10 to 13 ft., with a maximum of 17 ft. Using 3 rows of lights 14 ft. apart and 6 ft. om the wall (Fig. 116, I) will permit bench work to be done along the walls. The hts will be spaced 12 ft. apart in the length of the room so that the average spacing ll be 13 ft., giving 6 lights per bay.

From Table 197 a room 40 ft. wide by 120 ft. long by 15 ft. high gives a room index *D*.

From Table 198, assuming a light-gray wall, the reflection factor is 50 per cent.

From Table 199, using a glassteel diffuser, with room index *D* and 50 per cent wall d ceiling reflection factors, the maintenance factor is 0.70, and the coefficient of lization is 0.51. From Sec. **192** (12):

$$\text{Area per outlet} = \frac{40 \times 120}{30} = 160 \text{ sq. ft. per outlet}$$

From Sec. **192** (13):

$$\text{Lamp lumens per outlet} = \frac{20 \times 160}{0.51 \times 0.70} = 9{,}000$$

From Sec. **111** the lumen output of the 250-watt mercury lamp is 7,500 lumens. From . **118**, two 150-watt incandescent lamps are the smallest size which can be used with

this luminaire. Referring to Table 81, their total lumen output is $2 \times 2{,}600 = 5.$ lumens; or a total of 12,700 lumens including the mercury lamp. From Sec. **192** (

$$\text{Actual ft.-candles [For. (10), Sec. 191]} = \frac{12{,}700 \times 0.51 \times 0.70}{160} = 28 \text{ ft.-c.}$$

Since this is considerably greater than the 20 ft.-c. desired, consideration might given to spacing the outlets farther apart in the length of the building.

An arrangement of six units in the end and center bays with three units in each of other two bays (Fig. 116, II) would give a spacing of 15 and 16 ft. apart in that direc which is still within the maximum of 17 ft. The area per outlet would be $\frac{120 \times 4}{24}$ 200 sq. ft.

$$\text{Lamp lumens per outlet} = \frac{20 \times 200}{0.51 \times 0.70} = 11{,}200 \text{ lumens}$$

$$\text{Actual foot-candles} = \frac{12{,}700 \times 0.51}{200} \times 0.70 = 22.6 \text{ ft.-c.}$$

This gives an illumination which is still about 11 per cent more than required, wh is satisfactory in all respects, and somewhat more economical than the closer spacin

194. In designing a Cooper-Hewitt-lamp installation proceed in manner similar to that outlined in Sec. **193,** using for the Cooper-Hew lamp the lumens given in Table 106.

TABLES FOR INTERIOR ILLUMINATION DESIGN

195. Allowable Spacing between Light Sources

(General Electric Co.)

Ceiling height (or height in the clear), ft.	Spacing between outlets, ft.		Max. spacing between outside outlets and wall, ft.	
	Usual	Max. (for units at ceiling)	Aisles or storage next to wall	Desks, work-benches, etc., against wall
8	7	7½	Usually one-half actual spacing between units	3
9	8	8		3
10	9	9		3½
11	10	10½		3½
12	10–12	12		3½–4
13	10–12	13		3½–4½
14	10–13	15		4–5
15	10–13	17		4–5
16	10–13	19		4–6
18	10–20	21		4–6
20 and up	18–24	24		5–7

196. Mounting Height of Light Sources

(General Electric Co.)

Direct and semidirect lighting units				Semi-indirect and indirect lighting	
Actual spacing between units, ft.	Min. distance of units from floor, ft.	Desirable mounting height in industrial interiors	Desirable mounting height in commercial interiors	Actual spacing between units, ft.	Recommended suspension length (top of bowl to ceiling), ft.
7	8	12 ft. above floor if possible—to avoid glare, and still be within reach from stepladder for cleaning	The actual hanging height should be governed largely by general appearance, but, particularly in offices and drafting rooms, the minimum values shown in the second column should not be violated	7	1–3
8	8½			8	1–3
9	9			9	1–3
10	10			10	1½–3
11	10½			11	2–3
12	11			12	2–3
14	12½	Where units are to be mounted much more than 12 ft. it is usually desirable to mount the units at ceiling or on roof trusses		14	2½–4
16	14			16	3–4
18	15			18	3–4
20	16			20	4–5
22	18			22	4–5
24	20			24	4–6

197. Room Index Classification of Rooms According to Their Proportio

(General Electric Co.)

	Ceiling Height Ft.									
For semi-indirect and indirect lighting	9 and 9½	10 to 11½	12 to 13½	14 to 16½	17 to 20	21 to 24	25 to 30	31 to 36	37 to 50	
	Mounting Height above Floor, Ft.									
For direct and semi-direct lighting	7 and 7½	8 and 8½	9 and 9½	10 to 11½	12 to 13½	14 to 16½	17 to 20	21 to 24	25 to 30	31 to 36	3

Room width, ft.	Room length, ft.	Room index									
9 (8½–9)	8–10	*H*	*I*	*J*	*J*						
	10–14	*H*	*I*	*I*	*J*						
	14–20	*G*	*H*	*I*	*J*	*J*					
	20–30	*G*	*G*	*H*	*I*	*J*	*J*				
	30–42	*F*	*G*	*H*	*I*	*J*	*J*	*J*			
	42 and over	*E*	*F*	*G*	*H*	*I*	*J*	*J*			
10 (9½–10½)	10–14	*G*	*H*	*I*	*J*	*J*					
	14–20	*G*	*H*	*I*	*J*	*J*	*J*				
	20–30	*F*	*G*	*H*	*I*	*J*	*J*				
	30–42	*F*	*G*	*G*	*H*	*I*	*J*	*J*			
	42–60	*E*	*F*	*G*	*H*	*I*	*J*	*J*			
	60 and over	*E*	*F*	*F*	*H*	*H*	*I*	*J*			
12 (11–12½)	10–14	*G*	*H*	*I*	*I*	*J*	*J*				
	14–20	*F*	*G*	*H*	*I*	*J*	*J*				
	20–30	*F*	*G*	*G*	*H*	*I*	*J*	*J*			
	30–42	*E*	*F*	*G*	*H*	*I*	*J*	*J*			
	42–60	*E*	*F*	*F*	*G*	*H*	*I*	*J*			
	60 and over	*E*	*E*	*F*	*G*	*H*	*I*	*J*			
14 (13–15½)	14–20	*F*	*G*	*H*	*H*	*I*	*J*	*J*			
	20–30	*E*	*F*	*G*	*H*	*I*	*J*	*J*			
	30–42	*E*	*F*	*F*	*G*	*H*	*I*	*J*	*J*		
	42–60	*E*	*E*	*F*	*F*	*H*	*I*	*J*	*J*	*J*	
	60–90	*D*	*E*	*E*	*F*	*G*	*H*	*J*	*J*	*J*	
	90 and over	*D*	*E*	*E*	*F*	*F*	*G*	*J*	*J*	*J*	
17 (16–18½)	14–20	*E*	*F*	*G*	*H*	*I*	*J*	*J*			
	20–30	*E*	*F*	*F*	*G*	*H*	*I*	*J*			
	30–42	*D*	*E*	*F*	*G*	*H*	*H*	*J*	*J*		
	42–60	*D*	*E*	*E*	*F*	*G*	*G*	*I*	*J*	*J*	
	60–110	*D*	*E*	*E*	*F*	*G*	*G*	*I*	*J*	*J*	*J*
	110 and over	*C*	*D*	*E*	*E*	*F*	*G*	*H*	*I*	*J*	*J*
20 (19–21½)	20–30	*D*	*E*	*F*	*G*	*H*	*I*	*J*	*J*		
	30–42	*D*	*E*	*E*	*F*	*G*	*H*	*I*	*J*	*J*	
	42–60	*D*	*D*	*E*	*E*	*F*	*G*	*I*	*J*	*J*	*J*
	60–90	*C*	*D*	*E*	*E*	*F*	*G*	*H*	*J*	*J*	*J*
	90–140	*C*	*D*	*D*	*E*	*F*	*F*	*H*	*I*	*J*	*J*
	140 and over	*C*	*D*	*D*	*E*	*F*	*F*	*H*	*I*	*I*	*J*
24 (22–26)	20–30	*D*	*E*	*E*	*F*	*G*	*H*	*I*	*J*	*J*	
	30–42	*C*	*D*	*E*	*F*	*G*	*G*	*I*	*J*	*J*	
	42–60	*C*	*D*	*D*	*E*	*F*	*G*	*H*	*I*	*J*	*J*
	60–90	*C*	*D*	*D*	*E*	*F*	*F*	*H*	*I*	*J*	*J*
	90–140	*C*	*C*	*D*	*E*	*E*	*F*	*G*	*H*	*I*	*J*
	140 and over	*C*	*C*	*D*	*E*	*E*	*F*	*G*	*H*	*I*	*I*

Room Index Classification of Rooms According to Their Proportions

(*Continued*)

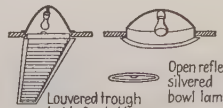
	Ceiling Height, Ft.									
For semi-indirect and indirect lighting	9 and 9½	10 to 11½	12 to 13½	14 to 16½	17 to 20	21 to 24	25 to 30	31 to 36	37 to 50	
	Mounting Height above Floor, Ft.									
For direct and semi-direct lighting	7 and 7½	8 and 8½	9 and 9½	10 to 11½	12 to 13½	14 to 16½	17 to 20	21 to 24	25 to 30	31 to 36	37 to 50
Room width, ft.	Room length, ft.	Room index									
30 (27–33)	30–42	C	D	D	E	F	G	H	I	J	J	
	42–60	C	C	D	D	F	F	H	H	I	J	
	60–90	B	C	C	D	E	F	G	H	I	J	J
	90–140	B	C	C	D	E	E	F	G	H	I	J
	140–180	B	C	C	D	E	E	F	G	H	I	J
	180 and over	B	C	C	D	E	E	F	G	H	I	J
36 (34–39)	30–42	B	C	D	E	F	F	H	I	I	J	
	42–60	B	C	C	D	E	F	G	H	I	J	J
	60–90	A	C	C	C	E	E	F	H	H	J	J
	90–140	A	B	C	C	D	E	F	G	H	I	J
	140–200	A	B	C	C	D	E	F	F	G	H	I
	200 and over	A	B	C	C	D	E	F	F	G	H	I
42 (40–45)	42–60	A	B	C	C	E	F	G	H	I	I	J
	60–90	A	B	B	C	D	E	F	G	H	I	J
	90–140	A	B	B	C	D	D	E	F	G	H	J
	140–200	A	A	B	C	D	D	E	F	G	H	I
	200 and over	A	A	B	C	D	D	E	F	F	G	I
50 (46–55)	42–60	A	A	B	C	D	E	F	G	H	I	J
	60–90	A	A	B	C	C	D	F	F	G	H	J
	90–140	A	A	A	C	C	D	E	F	F	G	I
	140–200	A	A	A	C	C	D	E	E	F	G	I
	200 and over	A	A	A	C	C	D	E	E	F	G	H
60 (56–67)	60–90	A	A	A	B	C	D	E	F	G	H	I
	90–140	A	A	A	B	C	C	D	E	F	G	H
	140–200	A	A	A	B	C	C	D	E	E	F	H
	200 and over	A	A	A	B	C	C	D	E	E	F	H
75 (68–90)	60–90	A	A	A	A	B	C	D	E	F	G	I
	90–140	A	A	A	A	B	C	D	E	F	F	H
	140–200	A	A	A	A	B	B	C	D	E	F	G
	200 and over	A	A	A	A	B	B	C	D	E	F	G
and over	60–90	A	A	A	A	B	C	D	E	F	G	H
	90–140	A	A	A	A	A	B	C	D	E	F	G
	140–200	A	A	A	A	A	B	C	D	E	F	G
	200 and over	A	A	A	A	A	B	C	C	D	E	F

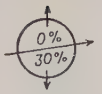
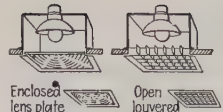
198. Reflection Factors of Colored Surfaces

Color	Reflection factor, per cent	Color	Reflection factor, per cent
at white	75–85	Light green	40–50
ory	70–75	Gray	30–50
ff	60–70	Blue	25–35
llow	55–65	Red	15–20
ght tan	45–55	Dark brown	10–15

199. Maintenance Factors and Coefficients of Utilization for Incandescent and Mercury Luminaires

(General Electric Co.)

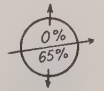
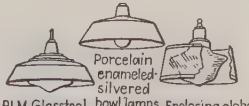
Type No.	Candlepower distribution	Distribution efficiency	Typical luminaires	Maintenance factor, av. conditions	Reflection factors: Ceiling	75 %			50 %			30 %	
					Walls	50 %	30 %	10 %	50 %	30 %	10 %	30 %	10 %
					Room index	Coefficients of utilization							
					Direct—Concentrating								
1			HIGH BAY OPEN REFLECTORS	.70	*J*	.40	.38	.36	.39	.38	.36	.39	.36
					I	.48	.46	.46	.47	.46	.46	.45	.43
					H	.51	.51	.50	.50	.50	.49	.50	.48
					G	.55	.54	.54	.54	.52	.52	.52	.51
					F	.58	.56	.55	.55	.55	.54	.55	.53
					E	.60	.59	.58	.59	.58	.57	.57	.56
					D	.64	.61	.60	.62	.60	.60	.60	.59
					C	.65	.63	.61	.63	.62	.60	.60	.60
					B	.65	.64	.63	.64	.62	.62	.62	.61
					A	.66	.65	.64	.64	.63	.62	.62	.62
2			 PARABOLIC POLISHED METAL REFLECTORS	.70	*J*	.29	.27	.26	.28	.27	.26	.28	.26
					I	.34	.33	.32	.34	.32	.32	.32	.31
					H	.37	.36	.36	.36	.36	.35	.36	.34
					G	.39	.39	.38	.38	.38	.37	.38	.36
					F	.41	.40	.39	.40	.39	.38	.39	.38
					E	.43	.42	.42	.42	.42	.40	.41	.40
					D	.46	.44	.43	.44	.43	.42	.42	.42
					C	.46	.45	.44	.45	.44	.43	.43	.42
					B	.47	.46	.45	.46	.44	.44	.44	.44
					A	.47	.46	.46	.46	.45	.44	.44	.44

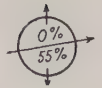
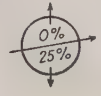
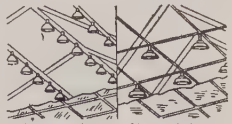
3			 PRISMATIC GLASS OR POLISHED METAL REFLECTORS	.70	*I*	.21	.20	.20	.20	.20	.19	.20	.19
					H	.22	.22	.21	.22	.21	.21	.21	.21
					G	.24	.23	.23	.23	.22	.22	.22	.22
					F	.25	.24	.24	.24	.23	.23	.23	.23
					E	.26	.25	.25	.25	.25	.24	.25	.24
					D	.27	.26	.26	.26	.26	.26	.26	.25
					C	.28	.27	.26	.27	.26	.26	.26	.26
					B	.28	.27	.27	.27	.27	.26	.26	.26
					A	.28	.28	.27	.28	.27	.27	.27	.26

Direct—Distributing

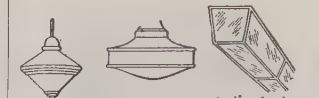
4			DISTRIBUTING TYPE OPEN REFLECTORS	.75	*J*	.34	.29	.24	.34	.29	.24	.28	.24
					I	.42	.38	.34	.42	.37	.33	.37	.33
					H	.46	.43	.39	.45	.42	.39	.42	.39
					G	.50	.47	.43	.49	.46	.43	.45	.42
					F	.53	.50	.46	.52	.49	.46	.48	.45
					E	.58	.55	.51	.57	.54	.51	.53	.51
					D	.62	.59	.56	.61	.58	.56	.58	.56
					C	.64	.61	.58	.63	.60	.58	.60	.58
					B	.67	.65	.63	.66	.64	.62	.63	.61
					A	.69	.67	.65	.67	.66	.64	.65	.63
5			DISTRIBUTING TYPE OPEN REFLECTORS	.75	*J*	.32	.28	.25	.32	.28	.25	.27	.25
					I	.40	.36	.34	.39	.35	.33	.35	.33
					H	.43	.39	.37	.42	.39	.37	.39	.37
					G	.46	.43	.41	.45	.43	.41	.43	.41
					F	.48	.45	.43	.47	.45	.43	.45	.43
					E	.52	.50	.48	.51	.49	.47	.49	.47
					D	.56	.54	.52	.55	.53	.51	.53	.51
					C	.57	.55	.53	.56	.54	.52	.54	.52
					B	.60	.58	.56	.59	.57	.55	.57	.55
					A	.61	.59	.57	.60	.58	.57	.58	.56

Maintenance Factors and Coefficients of Utilization for Incandescent and Mercury Luminaires (*Continued*)

Type No.	Candlepower distribution	Distribution efficiency	Typical luminaires	Maintenance factor, av. conditions	Reflection factors							
					Ceiling	75 %			50 %			30 %	
					Walls	50 %	30 %	10 %	50 %	30 %	10 %	30 %	10 %
					Room index	Coefficients of utilization							
Direct—Distributing (*Continued*)													
6				.75	*J*	.35	.30	.26	.34	.30	.26	.29	.26
					I	.44	.39	.36	.43	.38	.35	.38	.35
					H	.48	.44	.41	.46	.44	.40	.43	.40
					G	.51	.48	.45	.50	.47	.44	.46	.44
					F	.54	.51	.48	.52	.50	.47	.49	.47
					E	.59	.56	.53	.58	.55	.52	.54	.52
					D	.63	.60	.57	.62	.59	.57	.58	.57
					C	.65	.62	.59	.63	.61	.59	.60	.58
					B	.68	.65	.63	.66	.64	.62	.63	.62
					A	.69	.67	.65	.68	.65	.64	.64	.63
7			 LARGE AREA DIFFUSING REFLECTORS	.75 for silvered-bowl lamps .70 for others	*J*	.34	.31	.29	.34	.31	.29	.31	.29
					I	.42	.39	.38	.41	.38	.37	.38	.36
					H	.45	.43	.42	.44	.42	.41	.42	.41
					G	.48	.46	.45	.47	.46	.44	.45	.44
					F	.51	.49	.46	.49	.47	.46	.47	.46
					E	.54	.52	.50	.53	.51	.49	.51	.49
					D	.57	.55	.53	.56	.54	.53	.53	.53
					C	.59	.57	.54	.57	.55	.54	.55	.53
					B	.60	.58	.57	.58	.57	.56	.56	.56
					A	.61	.59	.58	.60	.58	.57	.57	.56

8			 LARGE AREA DIFFUSING PANELS	.70	*J*	.26	.22	.19	.25	.22	.19	.21	.19
					I	.32	.29	.26	.31	.28	.26	.28	.26
					H	.35	.32	.30	.34	.32	.30	.31	.30
					G	.38	.35	.33	.37	.35	.32	.34	.32
					F	.40	.37	.35	.38	.36	.35	.36	.35
					E	.43	.41	.39	.42	.40	.38	.40	.38
					D	.46	.44	.42	.45	.43	.42	.43	.42
					C	.48	.46	.43	.46	.45	.43	.44	.43
					B	.50	.48	.46	.48	.47	.46	.46	.45
					A	.51	.49	.48	.50	.48	.47	.47	.46
9			 LARGE AREA DIFFUSING PANELS	.65	*J*	.19	.16	.14	.18	.16	.14	.16	.14
					I	.23	.21	.19	.23	.20	.19	.20	.19
					H	.25	.23	.22	.25	.23	.22	.23	.22
					G	.27	.25	.24	.27	.25	.24	.24	.24
					F	.29	.27	.25	.28	.26	.25	.26	.25
					E	.31	.30	.28	.31	.29	.28	.29	.28
					D	.34	.32	.30	.33	.32	.30	.31	.30
					C	.35	.33	.32	.34	.32	.32	.32	.31
					B	.36	.35	.34	.35	.34	.33	.34	.33
					A	.37	.36	.35	.36	.35	.34	.34	.34
10			 COMBINATION SKYLIGHT	.60	*J*	.12	.10	.09	.12	.10	.09	.10	.09
					I	.14	.13	.12	.14	.13	.12	.13	.12
					H	.16	.15	.14	.16	.14	.14	.14	.14
					G	.17	.16	.15	.17	.16	.15	.15	.15
					F	.18	.17	.16	.18	.16	.16	.16	.16
					E	.20	.19	.18	.19	.18	.18	.18	.18
					D	.21	.20	.19	.20	.20	.19	.20	.19
					C	.22	.21	.20	.21	.20	.20	.20	.20
					B	.23	.22	.21	.22	.21	.21	.21	.20
					A	.23	.22	.22	.22	.22	.21	.22	.21

Maintenance Factors and Coefficients of Utilization for Incandescent and Mercury Luminaires (*Continued*)

Type No.	Candlepower distribution	Distribution efficiency	Typical luminaires	Maintenance factor, av. conditions	Reflection factors							
					Ceiling	75 %			50 %			30 %	
					Walls	50 %	30 %	10 %	50 %	30 %	10 %	30 %	10 %
					Room index	Coefficients of utilization							
					Semidirect								
11			Glass or metal louvered downlighting unit; Prismatic glass enclosing unit	.70	*J*	.33	.32	.28	.31	.27	.26	.28	.25
					I	.40	.37	.35	.38	.35	.33	.33	.31
					H	.44	.41	.39	.41	.39	.37	.37	.35
					G	.47	.45	.43	.44	.41	.40	.40	.38
					F	.51	.48	.45	.46	.44	.42	.42	.40
					E	.54	.51	.49	.50	.48	.45	.45	.43
					D	.58	.54	.51	.53	.50	.48	.48	.46
					C	.60	.57	.53	.55	.52	.49	.48	.47
					B	.62	.59	.57	.57	.54	.53	.51	.49
					A	.64	.61	.58	.59	.56	.54	.52	.51
					General Diffuse								
12			 Glass enclosing unit; Projecting luminous element cased opal panels	.70	*J*	.23	.19	.16	.21	.17	.15	.16	.14
					I	.29	.24	.22	.26	.22	.19	.21	.18
					H	.33	.28	.25	.29	.26	.23	.23	.21
					G	.37	.32	.28	.32	.28	.26	.26	.23
					F	.40	.35	.32	.35	.31	.28	.28	.26
					E	.44	.40	.36	.39	.35	.32	.32	.29
					D	.48	.43	.39	.42	.38	.35	.35	.32
					C	.51	.46	.42	.44	.40	.37	.37	.34
					B	.55	.50	.46	.48	.44	.41	.39	.37
					A	.57	.53	.49	.50	.46	.43	.41	.39

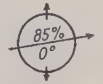
Semi-indirect

13			Glass enclosing or metal louvered unit	.70	*J*	.24	.20	.17	.21	.17	.15	.15	.14
					I	.29	.25	.23	.26	.22	.20	.20	.18
					H	.33	.29	.26	.28	.26	.23	.22	.20
					G	.37	.33	.30	.32	.28	.26	.24	.23
					F	.40	.35	.32	.34	.30	.28	.26	.23
					E	.44	.40	.36	.37	.34	.31	.29	.27
					D	.47	.43	.40	.40	.37	.34	.32	.30
					C	.50	.46	.42	.42	.39	.36	.33	.31
					B	.53	.50	.47	.44	.42	.40	.35	.34
					A	.56	.51	.49	.47	.44	.41	.37	.35
14			Glass enclosing or metal louvered unit	.70	*J*	.21	.17	.15	.16	.14	.12	.12	.09
					I	.26	.22	.20	.21	.18	.16	.15	.13
					H	.29	.26	.23	.23	.20	.19	.17	.15
					G	.33	.27	.26	.26	.23	.21	.18	.17
					F	.36	.32	.28	.28	.25	.23	.20	.20
					E	.39	.36	.32	.31	.28	.26	.22	.20
					D	.43	.38	.36	.33	.30	.28	.24	.22
					C	.45	.41	.38	.35	.32	.30	.25	.24
					B	.49	.46	.42	.37	.35	.34	.27	.26
					A	.51	.48	.45	.40	.37	.35	.28	.27

Indirect

15			Translucent glass or plastic bowls	.65	*J*	.18	.14	.13	.13	.11	.09	.08	.07
					I	.23	.19	.17	.17	.14	.12	.09	.07
					H	.26	.22	.20	.19	.16	.14	.12	.10
					G	.30	.25	.22	.21	.19	.17	.13	.12
					F	.32	.28	.25	.24	.21	.19	.14	.13
					E	.36	.32	.29	.27	.23	.21	.16	.15
					D	.40	.35	.32	.29	.26	.24	.18	.17
					C	.42	.38	.35	.30	.28	.26	.19	.18
					B	.46	.42	.40	.33	.31	.29	.21	.20
					A	.48	.44	.42	.35	.32	.31	.24	.21

Maintenance Factors and Coefficients of Utilization for Incandescent and Mercury Luminaires (*Continued*)

Type No.	Candlepower distribution	Distribution efficiency	Typical luminaires	Maintenance factor, av. conditions	Reflection factors							
					Ceiling	75 %			50 %			30 %	
					Walls	50 %	30 %	10 %	50 %	30 %	10 %	30 %	10 %
					Room index	Coefficients of utilization							
					Indirect (*Continued*)								
16			Dense glass or metal indirect unit	.60	*J*	.15	.12	.10	.10	.08	.07	.04	.04
					I	.19	.15	.14	.13	.10	.09	.06	.05
					H	.22	.18	.16	.14	.12	.10	.08	.06
					G	.25	.21	.18	.17	.14	.13	.08	.08
					F	.27	.24	.21	.19	.16	.14	.09	.08
					E	.31	.27	.25	.21	.18	.16	.10	.10
					D	.34	.30	.28	.22	.20	.19	.12	.11
					C	.36	.33	.30	.24	.22	.20	.13	.12
					B	.40	.37	.34	.26	.25	.23	.14	.14
					A	.42	.39	.37	.28	.26	.25	.16	.14
17			Silvered bowl lamp and shallow shield unit	.75	*J*	.17	.13	.11	.11	.09	.08	.05	.04
					I	.21	.17	.15	.14	.12	.10	.07	.06
					H	.25	.21	.18	.16	.14	.12	.08	.07
					G	.28	.24	.21	.20	.16	.14	.09	.08
					F	.31	.27	.23	.21	.18	.16	.10	.09
					E	.35	.31	.28	.24	.20	.19	.12	.11
					D	.39	.34	.31	.26	.23	.21	.14	.13
					C	.41	.37	.34	.27	.25	.23	.14	.14
					B	.46	.42	.39	.30	.28	.26	.16	.15
					A	.48	.44	.42	.32	.30	.28	.18	.16

18		65% 0%	.60	J	.13	.10	.09	.08	.07	.06	.04	.03
				I	.16	.13	.12	.11	.09	.08	.05	.05
				H	.19	.16	.14	.12	.10	.09	.06	.05
				G	.22	.19	.16	.15	.12	.11	.07	.06
				F	.24	.20	.18	.16	.14	.12	.08	.07
				E	.27	.24	.21	.18	.16	.14	.09	.08
				D	.30	.26	.24	.20	.18	.16	.10	.10
				C	.32	.29	.26	.21	.19	.18	.11	.10
				B	.35	.32	.30	.23	.21	.20	.12	.12
				A	.36	.34	.32	.25	.23	.21	.14	.12
			Deep metal bowls and troughs									
19		55% 0%	.60	J	.11	.09	.07	.07	.06	.05	.03	.03
				I	.14	.11	.10	.09	.08	.07	.04	.04
				H	.16	.13	.12	.10	.09	.08	.06	.04
				G	.18	.16	.13	.13	.10	.09	.06	.06
				F	.20	.17	.15	.14	.12	.10	.07	.06
				E	.23	.20	.18	.15	.13	.12	.08	.07
				D	.25	.22	.20	.16	.15	.14	.09	.08
				C	.27	.24	.22	.18	.16	.15	.09	.09
				B	.29	.27	.25	.19	.18	.17	.10	.10
				A	.31	.29	.27	.21	.19	.18	.12	.10
			Wall urn Column urn Wall box									
20		40% 0%	.55	J	.08	.06	.05	.05	.04	.04	.02	.02
				I	.10	.08	.07	.07	.06	.05	.03	.03
				H	.12	.10	.09	.08	.06	.06	.04	.03
				G	.13	.11	.10	.09	.08	.07	.04	.04
				F	.15	.13	.11	.10	.08	.08	.05	.04
				E	.17	.15	.13	.11	.10	.09	.06	.05
				D	.18	.16	.15	.12	.11	.10	.06	.06
				C	.19	.18	.16	.13	.12	.11	.07	.06
				B	.21	.20	.18	.14	.13	.12	.08	.07
				A	.22	.21	.20	.15	.14	.13	.08	.08
			Recessed coves Coffers									

Maintenance Factors and Coefficients of Utilization for Incandescent and Mercury Luminaires (*Continued*)

Type No.	Candlepower distribution	Distribution efficiency	Typical luminaires	Maintenance factor, av. conditions	Reflection factors							
					Ceiling	75%			50%			30%	
					Walls	50%	30%	10%	50%	30%	10%	30%	10%
					Room index	Coefficients of utilization							
21				.55	*J*	.05	.04	.03	.03	.03	.02	.02	.01
					I	.06	.05	.04	.04	.04	.03	.02	.02
					H	.07	.06	.05	.05	.04	.04	.02	.02
					G	.08	.07	.06	.06	.05	.04	.03	.02
					F	.09	.08	.07	.06	.05	.05	.03	.03
					E	.10	.09	.08	.07	.06	.06	.04	.03
					D	.11	.10	.09	.08	.07	.06	.04	.04
					C	.12	.11	.10	.08	.07	.07	.04	.04
					B	.13	.12	.12	.09	.08	.08	.05	.04
					A	.14	.13	.12	.10	.09	.08	.05	.05

199A. Maintenance Factors and Coefficients of Utilization for Fluorescent Luminaires

1				.75	*J*	.40	.38	.36	.39	.38	.36	.39	.36
					I	.48	.46	.46	.47	.46	.46	.45	.43
					H	.51	.51	.50	.50	.50	.49	.50	.48
					G	.55	.54	.54	.54	.52	.52	.52	.51
					F	.58	.56	.55	.55	.55	.54	.55	.53
					E	.60	.59	.58	.59	.58	.57	.57	.56
					D	.64	.61	.60	.62	.60	.60	.60	.59
					C	.65	.63	.61	.63	.62	.60	.60	.60
					B	.65	.64	.63	.64	.62	.62	.62	.61
					A	.66	.65	.64	.64	.63	.62	.62	.62

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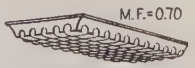
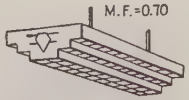
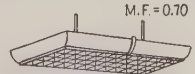
Maintenance Factors and Coefficients of Utilization for Fluorescent Luminaires (*Continued*)

Type No.	Candlepower distribution	Distribution efficiency	Typical luminaires	Maintenance factor, av. conditions	Reflection factors							
					Ceiling	75 %			50 %			30 %	
					Walls	50 %	30 %	10 %	50 %	30 %	10 %	30 %	10 %
					Room index	Coefficients of utilization							
5			 Plastic louvers Flat enamel reflector	.70	*J*	.33	.29	.27	.32	.29	.27	.29	.26
					I	.40	.37	.35	.38	.35	.34	.35	.33
					H	.43	.41	.39	.42	.39	.38	.39	.37
					G	.47	.44	.42	.45	.43	.41	.42	.40
					F	.50	.47	.44	.47	.45	.43	.45	.43
					E	.54	.51	.48	.51	.49	.47	.48	.46
					D	.57	.54	.51	.54	.52	.50	.51	.49
					C	.59	.56	.53	.56	.54	.51	.52	.51
					B	.61	.58	.56	.58	.55	.54	.54	.53
					A	.63	.60	.58	.60	.57	.55	.55	.54
6			 Metal louvers-Plastic sides	.70	*J*	.27	.24	.23	.25	.23	.22	.23	.21
					I	.33	.30	.29	.31	.29	.28	.28	.26
					H	.36	.34	.32	.34	.32	.31	.31	.29
					G	.39	.37	.35	.36	.34	.33	.33	.32
					F	.41	.39	.37	.38	.36	.35	.35	.34
					E	.44	.42	.40	.41	.39	.38	.37	.36
					D	.47	.44	.42	.43	.42	.40	.39	.38
					C	.48	.46	.43	.45	.43	.41	.40	.39
					B	.50	.48	.46	.46	.44	.43	.42	.41
					A	.51	.49	.48	.47	.46	.44	.43	.42

7		17% 65%	M.F. = 0.70 Glass louvers-White reflectors	.70	J	.33	.28	.26	.32	.28	.25	.26	.24
					I	.41	.36	.34	.39	.35	.32	.34	.32
					H	.45	.41	.38	.43	.40	.37	.38	.36
					G	.49	.45	.42	.46	.43	.40	.41	.39
					F	.52	.48	.45	.49	.46	.43	.44	.42
					E	.57	.53	.49	.53	.50	.47	.48	.46
					D	.61	.57	.53	.57	.54	.52	.52	.50
					C	.63	.59	.56	.59	.56	.54	.54	.52
					B	.66	.63	.60	.62	.59	.57	.56	.55
					A	.68	.65	.62	.64	.61	.59	.58	.56
8		23% 43%	M.F. = 0.65 Half cylinder plastic	.65	J	.22	.18	.15	.20	.17	.14	.15	.14
					I	.27	.23	.20	.25	.21	.19	.20	.18
					H	.30	.26	.24	.28	.25	.22	.23	.21
					G	.33	.30	.27	.30	.27	.25	.25	.23
					F	.36	.32	.29	.32	.29	.27	.27	.25
					E	.40	.36	.33	.36	.33	.30	.30	.28
					D	.43	.39	.36	.38	.36	.33	.33	.31
					C	.45	.41	.38	.40	.37	.35	.34	.33
					B	.48	.45	.42	.43	.40	.38	.37	.35
					A	.50	.46	.44	.45	.42	.40	.38	.37
9		29% 43%	M.F. = 0.65 Wedge unit-Glass	.65	J	.23	.19	.16	.21	.17	.15	.16	.14
					I	.28	.24	.22	.26	.22	.20	.21	.19
					H	.31	.27	.25	.29	.25	.23	.23	.21
					G	.35	.31	.28	.31	.28	.26	.26	.24
					F	.38	.34	.30	.34	.30	.28	.28	.26
					E	.42	.38	.34	.37	.34	.31	.31	.29
					D	.45	.41	.37	.40	.37	.34	.34	.32
					C	.48	.43	.40	.42	.39	.36	.35	.33
					B	.51	.47	.44	.45	.41	.39	.38	.36
					A	.53	.49	.46	.47	.43	.41	.39	.38

Maintenance Factors and Coefficients of Utilization for Fluorescent Luminaires (*Continued*)

Type No.	Candlepower distribution	Distribution efficiency	Typical luminaires	Maintenance factor, av. conditions	Reflection factors							
					Ceiling	75 %			50 %			30 %	
					Walls	50 %	30 %	10 %	50 %	30 %	10 %	30 %	10 %
					Room index	Coefficients of utilization							
10			Elliptical specular reflectors	.70	*J*	.34	.31	.29	.31	.29	.28	.29	.26
					I	.41	.38	.37	.38	.36	.35	.34	.32
					H	.45	.43	.41	.41	.39	.38	.37	.35
					G	.49	.46	.45	.44	.42	.41	.39	.38
					F	.52	.49	.47	.46	.44	.43	.41	.40
					E	.55	.52	.51	.49	.48	.46	.44	.42
					D	.59	.55	.53	.52	.50	.49	.46	.45
					C	.60	.58	.55	.54	.52	.50	.47	.46
					B	.62	.60	.58	.55	.53	.52	.48	.47
					A	.64	.62	.60	.57	.55	.53	.49	.48
11			 Plastic or glass side Louvered unit	.70	*J*	.23	.20	.18	.19	.17	.16	.16	.14
					I	.27	.25	.23	.23	.21	.20	.19	.18
					H	.30	.28	.26	.26	.24	.23	.21	.20
					G	.34	.31	.29	.29	.26	.25	.23	.22
					F	.36	.33	.31	.30	.28	.27	.24	.23
					E	.39	.37	.34	.33	.31	.29	.26	.25
					D	.42	.39	.37	.35	.33	.31	.27	.27
					C	.44	.41	.39	.36	.34	.33	.28	.27
					B	.47	.44	.42	.38	.36	.35	.30	.29
					A	.48	.46	.44	.39	.37	.36	.31	.30

200. Lighting Intensities Recommended for Industrial Interiors[a]

Occupancy	Illumination, ft.-c.
Aisles, stairways, passageways (10 watts per running foot)	2
Assembly:	
Rough	10
Medium	20
Fine	50–100
Extra fine	100 or more
Automobile manufacturing:	
Assembly line	50–100
Frame assembly	15–30
Body assembly	20–30
Body finishing and inspecting	100 or more
Bakeries	20
Bookbinding:	
Folding, assembling, pasting	10–20
Cutting, punching, stitching, embossing	20–30
Breweries:	
Brewhouse	5
Boiling, keg washing, etc.	10
Bottling	15–20
Candymaking	20–50
Canning and preserving	20
Chemical works:	
Hand furnaces, stationary driers and crystallizers	5
Mechanical driers and crystallizers, filtrations, evaporators, bleaching	10
Tanks for cooking, extractors, percolators, nitrators, electrolytic cells	15–20
Clay products and cements:	
Grinding, filter presses, kiln rooms	5
Molding, pressing, cleaning, trimming	10–20
Enameling	15–30
Glazing	20–30
Cloth products:	
Cutting, inspecting, sewing:	
1. Light goods	20–30
2. Dark goods	100 or more
Pressing, cloth treating (oilcloth, etc.):	
1. Light goods	10–30
2. Dark goods	20–50
Coal breaking, washing, screening	5–10
Dairy products	20
Engraving	100 or more
Forge shops:	
Welding	10
Foundries:	
Charging floor, tumbling, cleaning, pouring, shaking out	5
Rough molding and coremaking	10
Fine molding and coremaking	20
Garages:	
Storage:	
1. Live	10
2. Dead	2
Repair and washing	30–50
Glass works:	
Mixing and furnace rooms, pressing and Lehr glass-blowing machines	10
Grinding, cutting glass to size, silvering	20–30
Fine grinding, polishing, beveling, etching, inspection, etc	30–50
Glove manufacturing:	
Light goods:	
1. Cutting, pressing, knitting, sorting	10–20
2. Stitching, trimming, inspecting	20–30

[a] The values for this table have been selected from the recommendations of the "Handbook of Interior Wiring Design" and of the General Electric Co. The Handbook of Interior design was prepared and sponsored by the following organizations: (1) Artistic Lighting Equipment Association; (2) National Electrical Manufacturers' Association; (3) National Electrical Wholesalers' Association; (4) National Electrical Contractors' Association; (5) International Association of Electrical Inspectors; (6) Radio Manufacturers' Association; (7) Edison Electric Institute; (8) Illuminating Engineering Society.

The author recommends that, where ranges of values are given, the higher ones should be used with fluorescent lighting or that obtained by supplementary local illumination. Also the finer the detail to be observed the higher should be the illumination level selected.

Lighting Intensities Recommended for Industrial Interiors (*Continued*)

Occupancy	Illumination, ft.-c.
Glove manufacturing:	
Dark goods:	
1. Cutting, pressing, etc...	20–30
2. Stitching, trimming, etc.....	100 or more
Hangars, airplane:	
Storage, live.....	10
Repair department.....	30–50
Hat manufacturing:	
Dyeing, stiffening, braiding, cleaning, and refining:	
1. Light.....	10–20
2. Dark.....	20–50
Forming, sizing, pouncing, flanging, finishing, and ironing:	
1. Light.....	15–30
2. Dark.....	30–50
Sewing:	
1. Light.....	20–30
2. Dark.....	100 or more
Ice making:	
Engine and compressor room.....	10
Inspection:	
Rough.....	10–20
Medium.....	20–50
Fine.....	50–100
Extra fine.....	100 or more
Jewelry and watch manufacturing.....	100 or more
Laundries and dry cleaning....	20–30
Leather manufacturing:	
Vats.....	5
Cleaning, tanning, and stretching.....	10
Cutting, fleshing and stuffing.....	15–20
Finishing and scarfing.....	20–30
Leatherworking:	
Pressing, winding, and glazing:	
1. Light.....	10–30
2. Dark.....	20–50
Grading, matching, cutting, scarfing, sewing:	
1. Light.....	20–30
2. Dark.....	100 or more
Locker rooms.....	5–10
Machine shops:	
Rough bench and machine work.....	10–20
Medium bench and machine work, automatic machines, rough grinding, medium buffing and polishing.....	20–30
Fine bench and machine work, fine automatic machines, medium grinding, fine buffing and polishing..	50–100
Extra-fine bench and machine work, grinding.....	100 or more
Meat packing:	
Slaughtering.....	10
Cleaning, cutting, cooking, grinding, canning, packing	20
Milling, grain foods:	
Cleaning, grinding, and rolling.....	10
Baking or roasting.....	20
Flour grading.....	30
Offices:	
Private and general:	
1. No close work.....	10–20
2. Close work.....	20–50
Drafting Rooms.....	30–50
Packing and boxing.....	10
Paint manufacturing.....	10–20
Paint shops:	
Dipping, spraying, firing, rubbing, ordinary hand painting and finishing....	20
Fine hand painting and finishing.....	50–100
Extra-fine hand painting and finishing (automobile bodies, piano cases, etc.)..	100 or more
Paper-box manufacturing:	
Light.....	10–20
Dark.....	20–50
Storage of stock.....	5
Paper manufacturing:	
Beaters, grinding, calendering.....	10
Finishing, cutting, trimming.	20
Plating.....	10
Polishing and burnishing.....	15–30

Lighting Intensities Recommended for Industrial Interiors (*Continued*)

Occupancy	Illumination, ft.-c.
Power plants:	
Boiler, coal and ash handling, storage-battery rooms	5
Auxiliary equipment, oil switches and transformers	10–20
Switchboards, engines, generators, blowers, compressors	15–20
Printing industries:	
Matrixing and casting	10–20
Miscellaneous machines	15–30
Presses and electrotyping	20–50
Lithographing	50–100
Linotype, monotype, typesetting, imposing stone, engraving	50–100
Proofreading	100 or more
Receiving and shipping	10
Rubber manufacturing and products:	
Calenders, compounding mills, fabric preparation, stock cutting, tubing machines, solid-tire operations, mechanical-goods building, vulcanizing	10–20
Bead building, pneumatic-tire building and finishing, inner-tube operation, mechanical-goods trimming, treading	20–50
Sheet-metal works:	
Miscellaneous machines, ordinary bench work	15–50
Punches, presses, shears, stamps, welders, spinning, medium bench work	20–50
Tin-plate inspection	30–50
Shoe-manufacturing:	
Hand turning, miscellaneous bench and machine work	10–20
Inspecting and sorting raw material, cutting and stitching:	
1. Light	20
2. Dark	100 or more
Lasting and welting	20
Soap manufacturing:	
Kettle houses, cutting, soap chip and powder	10
Stamping, wrapping, and packing, filling and packing soap powder	20
Steel and iron mills, bar, sheets, and wire products:	
Soaking pits and reheating furnaces	5
Charging and casting floors	10
Muck and heavy rolling, shearing (rough by gage), pickling, and cleaning	10
Plate inspection, chipping	30–50
Automatic machines, light and cold rolling, wire drawing, shearing (fine by line)	15
Stone crushing and screening:	
Belt-conveyor tubes, main-line shafting spaces, chute rooms, inside of bins	5
Primary-breaker room, auxiliary breakers under bins	5
Screens	10
Storage-battery manufacturing:	
Molding of grids	10–20
Store and stockrooms:	
Rough bulky material	5
Medium or fine material requiring care	10–20
Structural-steel fabrication	10
Sugar grading	30
Testing:	
Rough	10–20
Fine	20–30
Extra-fine instruments, scales, etc	100 or more
Textile mills:	
Cotton:	
1. Opening and lapping, carding, drawing, roving, dyeing	10

Lighting Intensities Recommended for Industrial Interiors (*Continued*)

Occupancy	Illumination ft.-c.
Textile mills:	
Cotton:	
2. Spooling, spinning, drawing, warping, weaving, quilling, inspecting, knitting, slashing (over beam end)	20
Silk:	
1. Winding, throwing, dyeing	15–30
2. Quilling, warping, weaving, finishing:	
Light goods	15
Dark goods	30
Woolen:	
1. Carding, picking, washing, combing	10
2. Twisting, dyeing	10
3. Drawing-in, warping:	
Light goods	15–20
Dark goods	30–50
4. Weaving:	
Light goods	15–20
Dark goods	30–50
5. Knitting machines	20
Tobacco products:	
Drying, stripping, general	10
Grading and sorting	100 or more
Toilets and washrooms	5–10
Upholstering:	
Automobile, coach, furniture	20–30
Warehouse	5
Woodworking:	
Rough sawing and benchwork	10–20
Sizing, planing, rough sanding, medium machine and benchwork, gluing, veneering, cooperage	20–30
Fine bench and machine work, fine sanding and finishing	30–50

201. Lighting Intensities Recommended for Commercial Interiors[a]

Occupancy	Illumination ft.-c.
Armories:	
Drill sheds and exhibition halls. (This does not include lighting circuits for demonstration booths, special exhibit spaces, etc.)	10–30
Art galleries:	
General	5–10
On paintings (100 watts per running foot of usable wall area)	50–100
Auditoriums	5–10
Automobile showrooms	20–50
Banks:	
Lobby	10–20
Counters (75 watts per running foot including service for signs, small motor applications, etc.)	50–100
Offices and cages	20–50
Barber shop and beauty parlors (not including circuits for special equipment)	20–50
Bowling:	
Alley runway and seats	10
Pins (300 watts per set of pins)	30–50

[a] See note on Table 200.

Lighting Intensities Recommended for Commercial Interiors (*Continued*)

Occupancy	Illumination ft.-c.
Billiards:	
General	10
Tables (450 watts per table)	30–50
Churches:	
Auditoriums	5
Sunday-school rooms	10–20
Pulpit or rostrum	15–20
Clubrooms:	
Lounge	5–10
Reading rooms. (The above two uses are so often combined that the higher figure is advisable. It includes provision for convenience outlets)	30–50
Courtrooms	10–20
Dance halls (not including spectacular lighting, spots, etc.)	5
Drafting rooms	30–50
Fire-engine houses	2–10
Gymnasiums:	
Main floor	15
Shower rooms	10
Locker rooms	5
Fencing, boxing, etc	20
Handball, squash, etc	30
Halls and interior passageways (15 watts per running foot)	5
Hospitals:	
Lobby, reception room	10–20
Corridors (8 watts per running foot)	2–5
Wards (including allowance for convenience outlets for local illumination)	10
Private rooms (including allowance for convenience outlets for local illumination)	10
Operating room	20
Operating tables or chairs. (Major surgeries, 3,000 watt per area; minor surgeries, 1,500 watts per area. These two figures include allowance for directional control. Special wiring for emergency systems must also be considered)	100–1,000
Laboratories	20–50
Hotels:	
Lobby (not including provision for conventions, exhibits)	10–20
Dining room	5
Kitchen	10–20
Bedrooms (including allowance for convenience outlets)	10
Corridors (10 watts per running foot)	2–5
Writing room (including allowance for convenience outlets)	30–50
Libraries:	
Reading rooms (including allowance for convenience outlets)	30–50
Stack room (12 watts per running foot of facing stacks)	10
Moving-picture theater:	
During intermission	5
During pictures	0.1
(These figures do not include auxiliary circuits for color or other spectacular effects.)	
Museum:	
General	10
Local illumination of special exhibits (allow wattage for local illumination equal to total calculated for general lighting)	50–100
Office buildings:	
Private offices:	
1. No close work	10–30
2. With close work	20–50

Lighting Intensities Recommended for Commercial Interiors (*Continued*)

Occupancy	Illumination ft.-c.
General offices:	
1. No close work	10–30
2. With close work	20–50
File room, vault, etc	10–30
Reception room	5–20
Post offices:	
Lobby	10–20
Sorting, mailing, etc	20–30
Storage, file room, etc	10–30
Professional offices:	
Waiting rooms	10–20
Consultation rooms	20–30
Operating offices	20
Dental chairs (600 watts per chair)	30–50
Railways:	
Depot, waiting room	10
Ticket offices, general	10
Ticket counters (75 watts per running foot)	30–50
Rest room, smoking room	10
Baggage room	10
Concourse	5
Train platform	5
Restaurants, lunchrooms, and cafeterias:	
Dining area	10
Food displays (100 watts per running foot of counter, including service aisle)	30–50
Schools:	
Auditoriums	10
If used as a study hall	20–30
Class and study rooms	20–30
Drawing room	30–50
Laboratories	15–30
Manual training	20–30
Sewing room	30–50
Sight-saving classes	30–50
Showcases (40 watts per running foot)	50–100
Show windows:	
Large cities:[a]	
Brightly lighted district (350 watts per running foot of glass frontage)	200–500
Secondary business locations (250 watts per running foot of glass frontage)	100–200
Neighborhood stores (150 watts per running foot of glass frontage)	50–100
Medium cities:[a]	
Brightly lighted districts (250 watts per running foot of glass frontage)	100–200
Neighborhood stores (150 watts per running foot of glass frontage)	50–100
Small cities and towns[a] (150 watts per running foot of glass frontage)	50
Lighting to reduce daylight window reflections (750 watts per running foot of glass frontage)	500–1,000
Stores—department, specialty, and miscellaneous large:	
Main floor	20–50
Other floors	15–20
Stores in outlying districts	15
Theaters:	
Auditoriums (not including auxiliary circuits for color or other spectacular effects)	5
Foyer	10
Lobby	15–20
Wall cases (50 to 75 watts per running foot, depending on height and depth)	50–100

[a] Ten per cent reduction for glass on two sides. Twenty-five per cent reduction for glass on three sides. Forty per cent reduction for island windows.

INTERIOR-LIGHTING SUGGESTIONS

202. Residence Lighting.—In the lighting of the home, the decorative element should predominate. The lighting must, however, comply with the general rules of lighting (Sec. **175**) concerning color, shadows, glare, and illumination. A room in which yellow or red is the predominant color gives a warm cheerful impression, whereas a room furnished in blue tends to produce the opposite sensation. Shade and softened shadows are preferable to sharp shadows or to no shadows. It is especially important that glare be minimized.

Kitchen.—The kitchen requires plenty of well diffused light. Except for very large rooms one 100-watt or one 150-watt lamp in a diffusing-glass enclosed unit will furnish satisfactory general illumination. For exceptionally large rectangular rooms two units may be required. Unless the room is very small with light-colored walls and ceilings, the general illumination should be augmented by bracket or pendent lamps. A single light in the center of the kitchen usually compels the cook to work entirely in her own shadow, whether at the range, the sink, or the kitchen cabinet or table. A single bracket over the center of the sink or a bracket at each side of the sink is nearly always necessary to eliminate the shadows. In some cases it may be advisable to locate similar bracket lights at the kitchen cabinet and a pendent unit over the range.

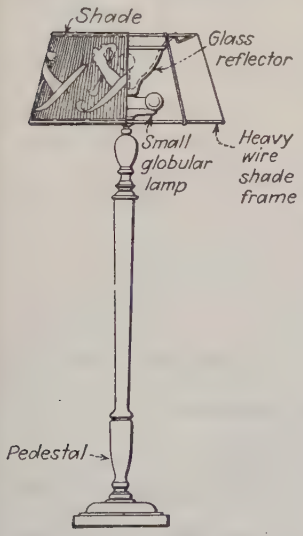


FIG. 117.—Indirect type decorative floor lamp for residence illumination.

Bedroom.—The illumination requirements of the bedroom are somewhat similar to those for the kitchen. General illumination should be provided by means of a centrally located ceiling unit of low brightness so that it will not be uncomfortable to the eyes of one lying in bed. Additional illumination should be provided at the dresser or bureau by means of either brackets or a portable lamp on each side of the mirror.

Living Room.—Although there is a general tendency at the present time to eliminate the ceiling fixture, it is the opinion of experts that there will be a reaction to this practice. The central ceiling fixture if of a properly shaded type is the most desirable means of obtaining the general level of illumination required for festive occasions. For a quiet evening at home a lower level of general illumination may be obtained by means of the indirect type of floor and table lamps (Fig. 117).

The chief function of bracket lamps is for ornamentation, and they should not be relied upon for providing the necessary light for useful purposes.

203. I.E.S. Better-sight Lamp, Specifications Summary

Type	Mazda lamp, watts	Approx. reflector diam., in.	Brightness[a]	Typical height[b] over-all, in.	Distance from center of lamp, in.						Min. light output in % of the bare-lamp lumens	
					12	18	24	30	36	48	Above the horizontal	Total
					Foot-candle illumination							
Study and reading (table)	100	8	No exposed surface for these lamps may exceed a brightness limit of 3 candles per sq. in. in specified directions from which the surface may be normally seen	28	30	20	10[c]	7	5	..	40	75
Study and reading (table)	50/100/150	9⅜		28	40	30	15[d]	10	7	..	40	75
Study and reading (floor)	100	8		58	30	20	10[c]	7	5	..	40	75
Study and reading (floor)	150 or 50/100/150	9⅜		58	40	30	15[d]	10	7	..	40	75
Semi-indirect	100/200/300 or 250 ind.	10		63	40	..	20	..	15	10	..	75
Indirect[e]	100/200/300 or 250	10	66 in. above and 2 ft. out, 3 candles per sq. in.[e]	66	..	..	....	..	..	10	..	75
End table[f]	100	8	½ candle per sq. in. below top of lamp[f]	23	30	25	20	10	..	..	10	65

In addition to the above, the I.E.S. Specifications cover safety and construction but not, however, decorative treatment.

[a] Brightness limit of ½ candle per sq. in. for shade applied to all types of lamps.

[b] The specifications do not set limits for shade or over-all heights.

[c] Normal illumination, 10 ft.-c. at 10 in. above table, 2 ft. out from shaft.

[d] Normal illumination, 15 ft.-c. at 10 in. above table, 2 ft. out from shaft.

[e] To avoid concentrated amounts of light above unit, the candle power directly upward is limited to 2½ times that emitted 45 deg. out.

[f] For the end-table lamp, the same 3 candles per sq. in. in brightness limits apply, except that 30 candles per sq. in. is allowed up to 36 in. above the floor, 2 ft. out from the shaft.

204. For reading or studying, an I.E.S. lamp should be used (Fig. 118). This lamp is made in a variety of types for either table or floor mounting according to specifications drawn up by the Illuminating Engineering Society (Table 203), from which it receives its name. It consists of a bulb mounted base down in a reflecting globe which is open at the top. A reflecting shade, which is white on the inside and has a wider flare at the bottom than the usual decorative lamp, conceals the reflecting globe

and spreads the light rays so that there is good illumination on the reading plane at least as far as 2 ft. from the lamp stem. Any manufacturer whose lamps meet the specifications of the Illuminating Engineering Society, as determined by tests in the Electrical Testing Laboratories, New York, may be licensed to use the I.E.S. certification tag. About half of the light output of this lamp is directed upward to the ceiling so that it produces general room illumination. The rest of the light passes through the globe and is reflected by the white shade down on the reading plane. The advantage of this lamp is that it produces a high level of illumination on the reading surface at a convenient distance from the lamp with sufficient general room illumination so that there is not too much contrast between the illumination on the printed page and on the walls of the room. There is no glare from the lamp, since the bulb and globe are shielded from the eyes by the shade. A summary of the principal specifications is given in Sec. 203.

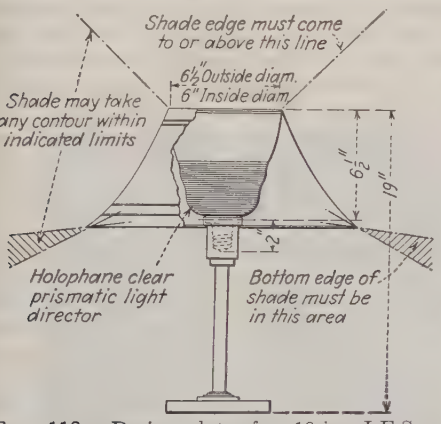


FIG. 118.—Design data for 19-in. I.E.S. lamp. (*Holophane Co.*)

205. Dining Room.—There are several satisfactory methods of illuminating the dining room, the selection depending upon personal taste. General illumination may be provided by means of a centrally located dome or indirect-lighting unit. Where a dome is employed, it should be hung just high enough above the table so that it will not obstruct the view of persons seated on opposite sides of the table, and low enough to hide the lamps from view entirely. The correct mounting height will usually be with the bottom of the dome 24 in. above the table top. Cove lighting by means of fluorescent lamps concealed in a trough a few inches down from the ceiling may be used. Wall brackets for decorative effects are also common.

Bathroom.—In the bathroom the illumination of the mirror requires the greatest consideration. For the best illumination of the mirror two small brackets should be employed mounted on opposite sides of the mirror slightly above the level of the face. If it is impossible to mount a unit on each side, one small bracket or fluorescent unit directly over the center of the mirror will produce the next best results. For small bathrooms the mirror wall brackets will supply sufficient general illumination for the rest of the room. In rooms of any appreciable size a central

enclosing unit should be used in addition to the bracket lamps. A sun lamp either centrally overhead or portable will provide healthful ultraviolet light for the winter months.

206. Store Lighting.—The object of the lighting in a store is twofold. Primarily, sufficient illumination must be provided to enable articles for sale to be seen plainly. But of almost equal importance is the advertising value. The lighting units should be so selected as to give a pleasing and cheerful appearance to the store as a whole, without glare. Stores may be divided into three classes: (1) the small store, in which efficiency is of first importance; (2) the large store, such as a department store, in which efficiency is necessary on account of the large areas to be lighted, but in which it must be balanced by artistic appearance, the result being a compromise between the two; (3) shops, large or small, in which the articles for sale are of a special type and the profits large enough so that even the most inefficient system can be afforded if it is sufficiently attractive to appeal to customers. The general requirements which must be satisfied are outlined in the following sections:

General Features of Store Lighting.—General lighting best meets the requirements for the lighting of stores. The lamps should be arranged symmetrically with respect to bays or pillars. Direct glare must be very carefully avoided. The position of the counters need not be considered in spacing the lamps. Local accurate-color-matching units are advisable at certain points, such as ribbon and piece-goods counters.

The intensity of illumination must be varied with the articles which are to be sold. Furniture requires well-diffused lighting of relatively low intensity. Colored dress goods, men's clothing, rugs and carpets, etc., require a high intensity. In many installations, side light is necessary and should be given especial attention in selecting types of units and reflectors. Cut glass and jewelry should be so lighted as to sparkle and glitter. This requires bare lamps and mirrored reflectors. Glare is to a certain extent, in this case, unavoidable, but the light units can usually be so located as to be out of the customer's range of vision when he is inspecting the ware. Pictures require a high intensity with the light units at such an angle that light will not be reflected from the surface of the painting, or from the glass, directly into the observer's eyes. Individual units or mirrored-trough reflectors, with fluorescent or tubular tungsten lamps, are ordinarily used.

Daylight fluorescent lighting units should be used to illuminate all items in which color under daylight is important, such as women's dresses, coats, and furs; men's suits and coats; draperies and curtains; tapestries; neckties; etc. Concealed colored fluorescent units should also be plentifully used for decorative effects.

207. Show-window Lighting.—Since the primary object of a show window is to attract attention, it should be illuminated to a sufficient intensity so that it will stand out from its surroundings. Table 209 gives

a guide to the proper spacing and size of lamps for show windows in different locations. Great care should be exercised in designing show-window lighting so that the lamps will be concealed from view. The lighting equipment should be concealed from view either by recessing in the ceiling or by means of a valance between the reflector and the front glass of the window. A good way to blind your prospective customer so he cannot see the goods on display in your window is to put exposed lamps around the window borders, suspend them from chandeliers, or so install them in the top of the window that his eye cannot escape them (see Fig. 119).

Shadows are necessary in window lighting in order to produce the desired effects, but they should not be too sharply defined. The light

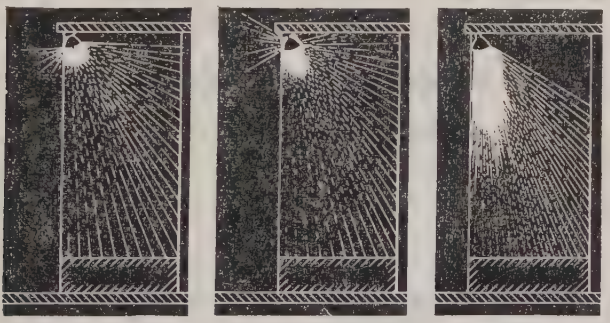


Fig. 119.—Illustrating good and bad window lighting.

should come from in front of the goods. If the lamps are placed in the middle of the show-window ceiling, the front of the goods displayed in the front of the window will be in darkness because of the shadows cast by them.

If the back of the display window is not boxed in, or if the window back is of glass, a valance or curtain should be provided to screen the window lamps from the store, and to prevent back reflection to an observer on the sidewalk.

Customers' attention should be attracted by illuminating selected articles with colored spotlights or arranging some of the circuits with color filters over the reflectors and putting them on dimmer cycles with motor-operated rheostats, or by having rotating color disks. Fluorescent units bring out the beauty of floral displays and give out very little heat. Daylight Mazda lamps bring out the beauty of polished aluminum and chromium-plated articles.

208. Show-window Lighting Equipment.—Angle-type prismatic or mirrored reflectors installed in a vertical position along the front upper

edge of the window are employed for show-window lighting. These special angle reflectors for show-window lighting are manufactured in many shapes in order to meet the varied requirements for the different types and sizes of windows. More than one row of reflectors with the lamps on several circuits are employed in many modern show windows so that a variety of lighting effects with respect to both intensities and colors may be obtained. Beautiful artistic effects may be produced by the use of colored light obtained by placing a gelatin screen of the desired color over the mouth of the reflector. Spotlights are often used in addition to the regular lighting units in order to illuminate special parts of a display to a high intensity. Spotlights will greatly enhance the effects produced. No general rules can be given concerning the shadows and color of light to be used. Innumerable effects can be obtained. By experiment, the display manager should determine the proper effect for each display to be lighted.

209. Spacing of Reflectors and Sizes of Lamps for Show-window Illumination

(Westinghouse Lamp Co.)

Population of city or town	Location of store	Spacing of reflectors, in.	Size of Mazda lamps, watts
5,000 or less	Main streets	15	150
	Side streets	18	150
5,000–50,000	Main streets	12	150–200
	Side streets	15	150
Above 50,000	Super white way	15	500
	Metropolitan district	12	200
	Main streets	12	150–200
	Side streets	15	150

210. Method of Computing Show-window Illumination.—The average intensity of illumination produced on the floor or back wall of a show window may be obtained from the following formula.

$$\text{Intensity of illumination in foot-candles} = \frac{A}{B} \qquad (11)$$

Wherein A = a factor depending upon the size and spacing of lamps (Table 211); and B = a factor depending upon the dimensions of the window and the type of reflecting equipment (Tables 212 and 213).

Example.—Determine the foot-candles of illumination produced on the walls and floor of a window 8 ft. high and 6 ft. deep lighted with 150-watt distributing units spaced 18 in. apart.

Solution.—From Table 211, factor A for 150-watt lamps spaced 18 in. apart is 1,470. From Table 213 for distributing reflectors, a depth of window of 6 ft. and a height of

window of 8 ft. give a value of 26 for factor B for the wall and a value of 13 for factor B for the floor.

$$\text{Average intensity on wall in foot-candles} = \frac{A}{B} = \frac{1,470}{26}$$
$$= 56.5 \text{ ft.-c.}$$
$$\text{Average intensity on floor in foot-candles} = \frac{A}{B} = \frac{1,470}{13}$$
$$= 113 \text{ ft.-c.}$$

211. A Factors
(Curtis Lighting, Inc.)

Reflector spacing, in.	Sizes of lamps, watts				
	100	150	200	300	500
	A factors				
12	1,350	2,200	3,200		
15	1,080	1,760	2,560	4,000	7,520
18	900	1,470	2,130	3,330	6,270
24	675	1,100	1,600	2,500	4,700
30	540	880	1,280		
36	450	730			

212. B Factors for Concentrating Reflectors
(Curtis Lighting, Inc.)

Height of window, ft.		Depth of window, ft.							
		2	3	4	5	6	8	10	12
		B factors for concentrating reflectors							
4	Wall	18	26	35	60	125	165	250	400
	Floor	5	6	7	8	9	12	15	18
6	Wall	18	27	38	41	55	80	165	250
	Floor	6	7	8	10	11	14	16	20
8	Wall	18	27	38	40	50	70	125	200
	Floor	11	9	9	11	12	15	18	20
10	Wall	20	29	38	45	50	70	100	140
	Floor	13	10	10	11	13	15	18	20
12	Wall	24	30	38	45	55	75	85	110
	Floor	13	12	12	13	13	16	19	21
14	Wall	28	31	38	45	55	75	80	105
	Floor	13	13	14	14	15	17	20	22

213. B Factors for Distributing Reflectors
(Curtis Lighting, Inc.)

Height of window, ft.		Depth of window, ft.							
		2	3	4	5	6	8	10	12
		B factors for distributing reflectors							
4	Wall	10	13	17	21	25	33	45	55
	Floor	6	7	8	9	10	12	15	17
6	Wall	11	15	19	22	26	35	38	55
	Floor	8	8	9	10	11	13	16	18
8	Wall	13	16	18	19	26	33	41	50
	Floor	11	11	12	12	13	15	18	20
10	Wall	16	18	21	23	27	35	41	50
	Floor	14	14	14	15	15	17	20	21
12	Wall	18	20	22	25	29	33	41	50
	Floor	19	18	17	17	17	18	20	22
14	Wall	21	23	25	28	31	41	43	50
	Floor	20	20	20	20	20	20	23	25

214. Showcase Lighting.—The intensity of illumination for showcase should be about four times that of the general store. Individual show case reflectors or trough-type reflectors installed along the front uppe edge of the case as near as possible to the front glass will give satisfactory results. The individual reflectors are spaced on 12- to 24-in. center with from 25- to 60-watt Type A lamps. With the trough reflector 25- to 50-watt tubular lamps spaced 12 to 24 in. apart are employed Fluorescent lamps are easily concealed, keep the showcase cool, giv high levels of illumination, and bring out color effects with excellen results.

215. Office Lighting.—As office work is usually performed during th daylight hours, any artificial illumination is usually in conjunction wit the available daylight. Since practically all the work done in an offic is on plane surfaces such as papers, books, etc., shadows are not onl unnecessary but are objectionable. Also, since the employees must us artificial illumination for long periods of time, the glare should be mini mum. The above requirements render the indirect, or the very dense bowl, semi-indirect units especially suitable for office illumination. Th units should, as a general rule, be given a closer spacing than for othe classes of service. This will produce a more gradual shading of an shadows and will also afford a greater flexibility in desk and partitio arrangement.

216. Specific desk lighting should in general be avoided. This is particularly true in large offices in which there are a number of desks. A much better plan is to provide, as outlined under Office Lighting, a

FIG. 120.—I.E.S.-type desk lamp for special office work. (*General Electric Co.*)

general illumination sufficiently bright to render individual desk lighting unnecessary. Specific desk lighting should generally be restricted to cases where one or two desks are located in an office chiefly used for other purposes which permit of a comparatively low degree of illumination or for cases where very close continuous work is performed, requiring 40 ft.-c. or more (Fig. 120).

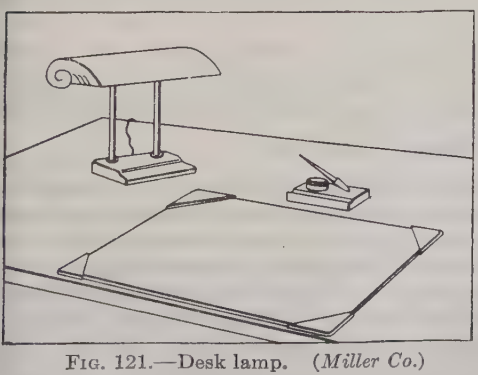


FIG. 121.—Desk lamp. (*Miller Co.*)

Portable desk lamps should preferably be of the fluorescent (Fig. 121), polarized-light, or I.E.S. types in order to give a good even illumination over the desk top without glare and with the light source concealed. An I.E.S. style lamp mounted on a swinging bracket is desirable where a lamp on the desk would be in the way of the work or

where a typewriter or calculating machine is used at one side of the desk, and the illumination must be adjusted between the desk top and the machine (Fig. 122).

217. Lighting Codes and Legislation.—A few states, including California, Oklahoma, Idaho, Ohio, Kentucky, Oregon, Maryland, Washington, Massachusetts, Wisconsin, Pennsylvania, New Jersey, and New York, have enacted statutes or lighting codes regulating lighting in industrial plants. Since it is the intention of the states only to protect the welfare of the citizens against undue accident hazard, the illuminations required by the statutes are usually much too low for the best efficiency. Any lighting installation planned according to the principles set forth in this division will in all probability satisfy any state code. However, before a lighting installation is made in a factory or industrial plant the designer should fully acquaint himself with any appertaining legislation

FIG. 122.—I.E.S. lamps on swinging brackets for illuminating keypunch machines. (*General Electric Co.*)

STREET LIGHTING

218. General Requirements for Street Lighting.—In all classes of street lighting it is desirable to have (1) uniform illumination, (2) good diffusion to prevent sharp shadows, and (3) low intrinsic brilliancy to minimize glare. Since the utilitarian problem in street lighting is to expend the available money so that the most effective feasible installation will result, it is not usually feasible to attain all these desirable conditions. Ordinarily, the appropriation is not sufficiently large to provide a great enough number of units to secure uniform illumination. The units must, then, be so selected, located, and mounted that glint, shadows, and silhouette effect may be utilized to aid the visibility. Glint assists in increasing the apparent brilliancy of a specularly reflecting street and

also reveals puddles on the sidewalk. Shadows are effective in locating small obstructions such as stones, curbs, holes, etc. Silhouette effect is the greatest aid in discerning large objects on the road or sidewalk such as vehicles, persons, posts, etc. Direct light is necessary to ensure recognition of the features of a passer-by.

219. Recommended Practice in Street Lighting.—The Committee on Street and Highway Lighting of the Illuminating Engineering Society has developed from studies and investigations of test and statistical data a general set of rules to serve as a technical basis upon which effective street lighting may be designed. The major purposes of street lighting as formulated by the Committee are:

1. To promote safety and convenience in the streets at night through adequate visibility.

2. To enhance the community value of the street.

3. To increase the attractiveness of the street. Underlying all other objectives, the fundamental purpose of street lighting is, through good visibility, to promote the safer use of streets.

219A. In designing an installation that will provide effectively the illumination required for the safe use of a street, a careful study of the problem from the following points of view is particularly necessary:

1. Traffic.—Character, speed, and volume of vehicular traffic and of pedestrian traffic.

2. Type of Street.—Classification according to use of street and of abutting property.

3. Dimension and Design.—Width of street and sidewalk areas. Curb contours or absence of curbs.

4. Street Surface.—Type, color, and reflection characteristics of paved or unpaved surfaces.

5. Buildings.—Predominating type of construction and character of use.

6. Transportation.—Public transportation facilities by street railway or buses.

7. Parking.—Location of parking lanes and amount and method of parking.

8. Trees.—Presence or absence, kind and height of trees, spread of branches over street and sidewalk, and height of lower branches; location on lot line or near curb.

9. Due consideration must also be given to available funds and aesthetic requirements.

220. The mounting height of a given luminaire (General Electric Co.) establishes the length of roadway included within the cone of light delivered by the unit. It must be considered, therefore, with respect to the spacing, if the desired uniformity of illumination and pavement reflections are to be obtained. Ratios of height to spacing vary from approximately 1:5 to 1:8, depending upon the photometric character-

istics of the luminaire. The distance away from the unit at which the direct light from it is shut off is also a function of the mounting height and must be considered in connection with probable glare conditions. In general, highway lighting luminaires if mounted 25 to 30 ft. above the roadway give satisfactory results. Practical consideration must also be given to cost, accessibility, and other factors.

The following table gives minimum acceptable mounting heights:

220A. Minimum Acceptable Mounting Heights for Luminaires
(Illuminating Engineering Society)

Lamp size, lumens	When using luminaires of max. concentration (beam c.p. approx. $\frac{8}{10}$ of lumen rating), ft.[a]	When using semi-concentrating luminaires (beam c.p. equals $\frac{3}{10}$ of lumen rating), ft.[b]	When using diffusing globes only (max. c.p. approx. $\frac{1}{10}$ of lumen rating), ft.
1,000[c]	15	15	15
2,500[d]	18	18	18
4,000	20	18	18
6,000	22	18	18
10,000	25	21	18
15,000	28	24	18
25,000	33	27	20

Observe that the above are recommended minimum mounting heights. Higher mounting heights than these generally are preferable.

[a] For example, a reflector-refractor type of luminaire providing this high degree of concentration.

[b] There are other luminaires which have been designed to give some degree of light redirection with reflecting or refracting equipment (sometimes using outer globes) which do not attain the high degree of concentration defined in Column 2. From a glare standpoint these can be mounted somewhat lower as indicated.

[c] The 1,000-lumen lamps are to be used for between-intersection lighting only, on very light traffic streets and in alleys. There are no conditions of street lighting prevailing in the United States which justify the use of smaller than 1,000-lumen lamps. The 2,500-lumen lamp is the smallest size which may be used with good economy.

[d] On forested streets a 15-ft. mounting height for 2,500-lumen lamps may be permissible, provided close spacing is used with post-top units.

220B. Classification of Traffic
(Illuminating Engineering Society)

Classification	Volume of Vehicular Traffic (Max. Night Hour in Both Directions)
Very light	Under 150
Light	150– 500
Medium	500–1,200
Heavy	1,200–2,400
Very heavy	2,400–4,000
Heaviest	Over 4,000

220C. Lumens per Square Foot (Foot-candles) Recommended for Various Types of Roadways Carrying Traffic of Various Degrees of Density

(Illuminating Engineering Society)

Type of roadway	Very light traffic		Light traffic		Medium traffic		Heavy traffic		Very heavy traffic	
	Av.	Min.	Av.	Min.	Av.	Min.	Av.	Min.	Av.	Min.
Principal business streets....	...	....	0.4	0.1	0.8	0.2	1.2	0.3	1.5	0.4
Secondary business streets...	...	....	0.3	0.07	0.6	0.15	1.0	0.25	1.3	0.3
Through high-speed arteries (other than business streets)	...	....	0.3	0.07	0.6	0.15	1.0	0.25	1.3	0.3
Express freeways and viaducts.....	...	....	...	....	0.4	0.1	0.8	0.2	1.2	0.3
Residence streets.....	0.1	0.02	0.2	0.05	0.4	0.1				
Industrial warehouse streets.	0.1	0.02	0.2	0.05	0.4	0.1				

NOTE.—These recommendations apply where pavement-reflection characteristics are favorable, as in the case of light concrete or light-finished asphalt. Somewhat higher foot-candle values should be employed where street-surface reflections are less favorable.

220D. The effectiveness of a luminaire is determined by the amount of light delivered to useful areas, and not by the total output. The amount of light delivered to useful areas divided by the total amount generated is called utilization efficiency and is obtained by the formula

$$\text{Utilization efficiency} = \frac{\text{effective lumens}}{\text{generated lumens}} \qquad (12)$$

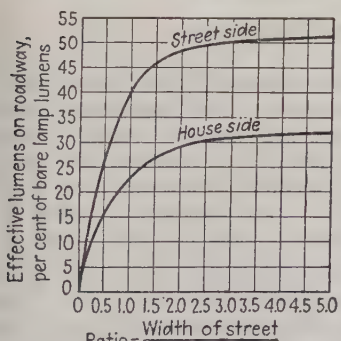


FIG. 123.—Effective lumens on roadway. (*General Electric Co.*)

For convenience a chart of utilization efficiency may be prepared for a luminaire, and from this chart average intensity for a given installation computed. Such a chart for the General Electric Form 86 Novalux Highway-lighting Luminaire is shown in Fig. 123. The average foot-candle intensity is computed from the formula:

$$\text{Average foot-candles} = \frac{\text{effective lumens}}{\text{spacing} \times \text{street width}} \qquad (13)$$

The value of foot-candles obtained from For. (13) should then be checked against the recommended values given in Table 220C.

221. Recommended Lamp Size, Mounting Height, and Spacing of Street-lighting Units
(Illuminating Engineering Society)

Street classification[a]	Lumens	Mounting height, ft.	Spacing measured along middle line of street, ft.	
Alleys	1,000	15	150–200	Staggered
Very light traffic	1,000	15	90–110	Staggered
	2,500	20–22	130–170	Staggered
	4,000	25–30	200–250	Center
Light traffic	2,500	16–18	100–120	Staggered
	4,000	20–25	130–170	Staggered
	6,000	22–25	130–170	Staggered
Medium traffic	6,000	20–25	100–120	Staggered
	10,000	22–27	130–170	Staggered
	15,000	25–30	130–170	Staggered
Heavy traffic	10,000	24–28	100–150	Opposite
	10,000	24–28	75– 90	Staggered
	15,000	24–28	150–180	Opposite
Very heavy traffic	15,000	25–30	100–150	Opposite
Heaviest traffic	15,000	25–30	100	Opposite

[a] Because of greater street widths, larger lamps or closer spacings than shown usually are required on business streets to produce desired results. Among the foregoing the larger lamps or the closer spacings are appropriate on business streets.

221A. Location and spacing of street-lighting units are shown in Figs. 124 and 125.

222. Incandescent, combination mercury-vapor and incandescent, and sodium-vapor lamps provide the most economical illumination for streets. In cities the incandescent lamp is the most generally used because of its good white-light qualities. The mercury-vapor and incandescent combination provides the good detail-revealing quality and high-lumen output of the mercury lamp. The incandescent lamp is added to correct the sallow color effect of the greenish-yellow mercury light and to provide light during the starting period of the mercury-vapor lamp. Some of the smaller cities are using this type. The sodium-vapor lamp (see Secs. **119** and **120**) has about 2½ times the lumen output of the incandescent lamp and at the same time gives a monochromatic yellow light which is excellent in showing up details of the road and in piercing fog. Bright automobile headlights are unnecessary where the highway is lighted with these lamps. The yellow color gives a person's skin a very sallow appearance so that it is undesirable in shopping areas where pedestrians congregate and should be kept in a good frame of mind. It is excellent for lighting of main automobile thoroughfares in rural sections and on city approaches. It is also desira-

ble at tunnel entrances, grade crossings, bridges, and other places hazardous to traffic.

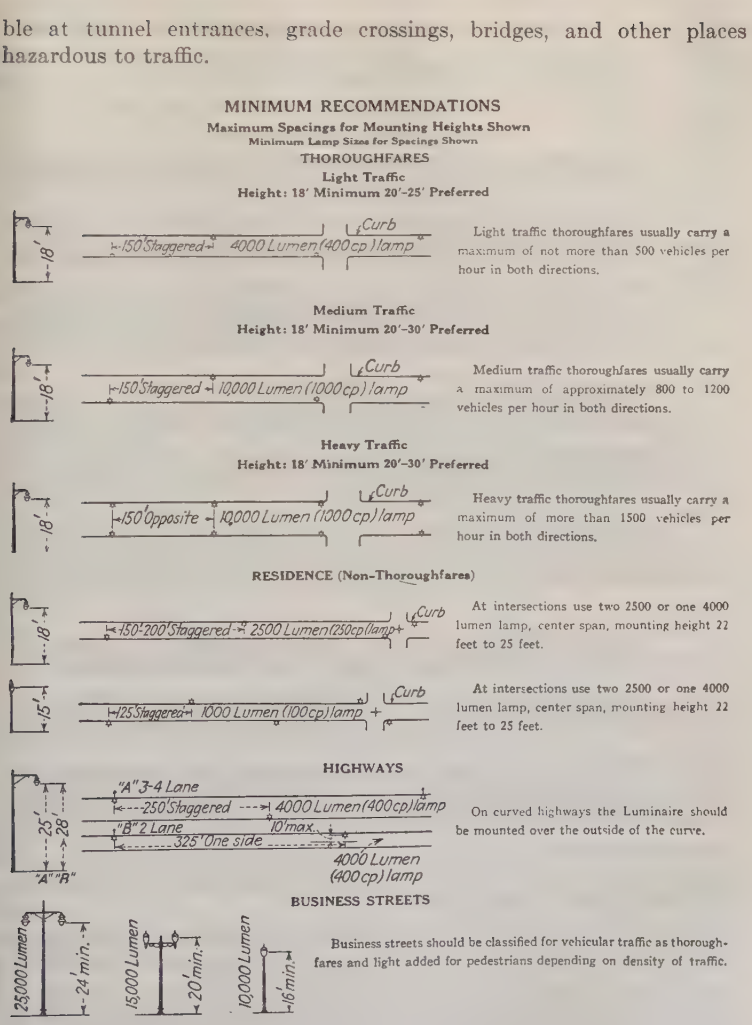
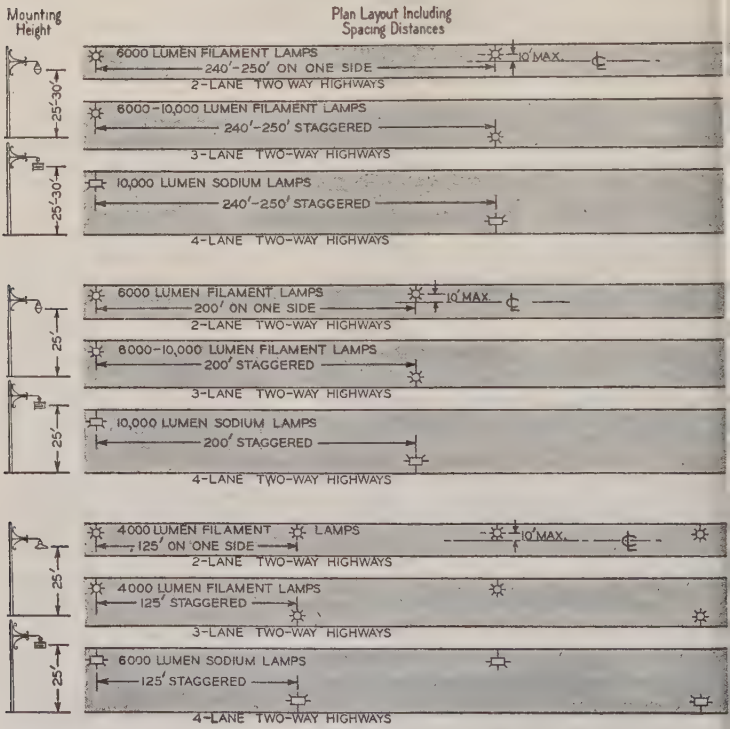


FIG. 124.—Minimum recommendations for location and spacing of street lighting units. (*Illuminating Engineering Society.*)

When multiple incandescent lamps are employed, they are of the ordinary general-lighting-service type [refer to Table 80 (clear-glass bulb) for the multiple lamps available and to Table 82 (street series service) for the series lamps].

Minimum Recommendations Specified By

I.E.S. HIGHWAY LIGHTING CODE



TYPES OF PAVEMENT. The illumination here recommended is for pavements permanently light in color and is on the order of 0.2 to 0.5 lumens per square foot of pavement. Recommendations for darker oil-polished surfaces are of 0.3 to 1.0 lumens per square foot. Very dull black pavements require 1.0 to 2.0 lumens per square foot of pavement and specialized lighting treatment.

VARIATIONS IN ARRANGEMENTS. Recommended illuminations may be obtained with larger illuminants on wider spacings or with smaller ones spaced more closely. Selection of spacing may vary with local circumstances. Lamps should be mounted at least 25 feet above the grade and over the pavement, as no practical increase in lamp size along the side of the highway compensates for the resultant loss of effectiveness.

PRINCIPLES USED IN PRACTICE. The following are not specified in the code but have been found valid and in keeping with those of the code. Mount lamps over the pavement preferably 5 feet from its edge. The best arrangement where practical is a row over the center of each lane. On curves the lamps should be mounted on the outside. For two-lane highways a staggered arrangement is preferred. For three-lane and wider highways, staggering is necessary for spacings greater than 70 feet; for smaller ones, opposite arrangements may be used. Extremely wide light distribution from sodium lamp luminaires commends their use on four-lane or wider highways.

FIG. 125.—Minimum recommendations for locations, spacing, and size o lamps for highway lighting. (*Illuminating Engineering Society.*)

223. Use of Mercury-vapor Lamps (General Electric Co.).—The light source is a tubular mercury-vapor bulb supported in a tubular jacket for protection against drafts and the hazards of handling. This bulb contains argon gas for starting, and a carefully measured quantity of mercury. The lamp operates from conventional lighting circuits when provided with a suitable reactor or transformer to regulate the current.

At first the glow is pale blue. Full light output is reached in about 10 min., and the discharge becomes a very hot, brilliant arc stream. Operation within 10 deg. of vertical is necessary to keep the heat of the discharge from melting the glass. Horizontal operation is possible but involves complex auxiliary equipment.

Mercury lamps are generally used in combination with incandescent lamps (Fig. 126) to provide heat to ensure reliable starting of the mercury

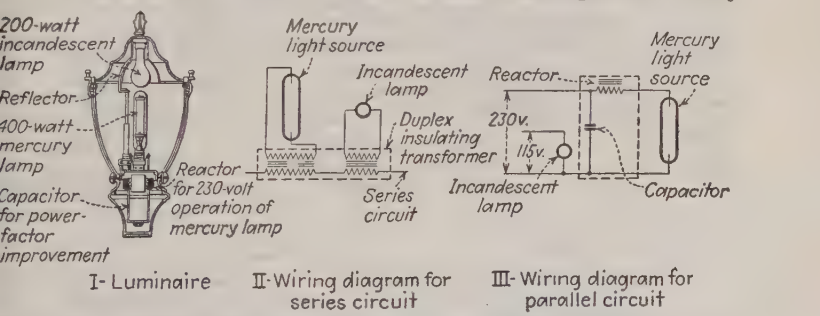


FIG. 126.—Combination mercury-incandescent street lamp. (*General Electric Co.*)

lamps at subzero temperatures, to correct partially the quality of light in the vicinity of the luminaire, and to provide some illumination in case the mercury lamp should not light immediately. In this connection it should be noted that after a brief power interruption there will be approximately 20 min. delay in the restarting of the mercury lamp, since it must cool off before it will restart. For maximum efficiency in the performance of its intended functions, a single incandescent lamp is mounted above the mercury lamp.

These luminaires give a symmetrical light distribution especially well suited to many business districts of cities. They can be used wherever the local situation will justify 10,000- to 25,000-lumen incandescent lamps. In some cases mercury-incandescent luminaires will result in lower over-all cost of street lighting—in other cases they may not. For an accurate indication of comparative costs for any particular project, it is essential to consult someone familiar with local conditions—the central-station company or the municipal lighting plant.

224. Street-lighting systems may be supplied with power in either of two ways: (1) through a multiple or constant-voltage system or (2)

through a series or constant-current system. With the multiple syste the supply circuit is maintained at approximately constant voltag In city lighting the lamps may be supplied from the same networ power-supply mains used for residential and commercial customer In rural districts an occasional group of lights at an intersection o danger point may be supplied from high-voltage feeders through a independent step-down transformer. With the series system the seri of lamps is supplied from a constant-current regulating transformer (s Div. 6 on Transformers). This automatically controls the current an

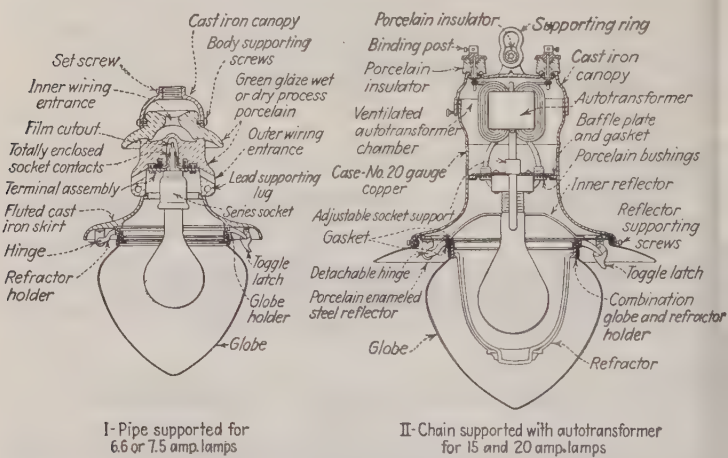


FIG. 127.—Enclosing globe street-lighting fixtures. (*Westinghouse Electr & Manufacturing Co.*)

voltage of the circuit and maintains a constant current regardless of th number of lamps burning. This system is normally used to suppl continuous systems of lights in residential districts, on parkways, o along highways, where it is not convenient to connect to low-voltag circuits. The current is normally 6.6 amp. with a maximum circu voltage of about 5,000 volts. A series circuit is commonly used wit sodium-vapor lighting, a multiple circuit with mercury-vapor, an either type with incandescent lamps. Mercury-vapor lamps may b supplied from a series circuit using reactor-type insulating transforme (see Fig. 126, II).

225. Film cutouts (Westinghouse Electric & Manufacturing Co.) a used on series circuits to ensure continuity of the circuit and to preve radio and telephone interference caused by harmonic voltages after lamp failure.

Each film cutout (Fig. 127, I) is inserted between the series socke prongs and is consequently in parallel with the lamp. It acts as a insulator at voltages somewhat higher than the normal lamp voltag

yet upon failure of the lamp it breaks down at a value below the open-circuit voltage of the line.

With the tendency to increase current and voltage ratings of street-lighting circuits and lamps, the proper application of film cutouts and their correct functioning becomes of extreme importance. The film cutouts are now recognized as an important connecting link in the system, and their failure to operate properly may cause expensive and serious lamp outages, possible damage to equipment, and both radio and telephone interference due to harmonic voltages.

The film cutouts function as follows:

1. They break down immediately upon failure of the lamp filament (owing to burnout or mechanical damage) and ensure continuity of the circuit by short-circuiting the socket prongs.

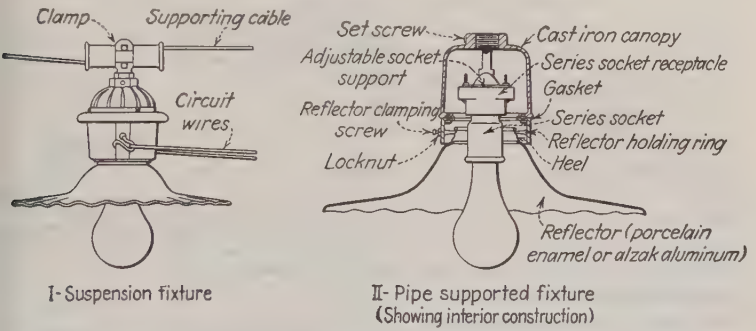


FIG. 128.—Radial-wave open reflectors for street lighting. (*Westinghouse Electric & Manufacturing Co.*)

2. The short circuit established by the broken-down film cutout is positive and permanent. Its current-carrying capacity is sufficient to avoid excessive voltage (IR) drop, thus eliminating unnecessary line losses, radio and telephone interference, and overheating of the socket and receptacle.

226. Autotransformer.—To secure the full advantage of the higher efficiency type of series incandescent lamp, a larger current is necessary than is usually available in the ordinary series circuit. To obtain this current, a special autotransformer is used (Fig. 127, II). The standard winding is for a 6.6-amp. primary with an extra tap provided for use on 7.5-amp. circuits.

Taps are provided on the standard 10,000-lumen autotransformer to take care of 6,000-lumen 20-amp. lamps and on the standard 6,000-lumen autotransformer to take care of 4,000-lumen, 15-amp. lamps. Windings for other current ratings may be obtained.

227. A reflector should always be used with any street-lighting lamp. Where no reflector is used a large portion of the light generated is pro-

jected above the lamp into the air and is wholly ineffective in lightin the street. A lamp hung so low that it lies within the range of vision of near-by observer will be a source of glare if it is not provided with proper reflector. The most effective type of reflecting equipment i street lighting, especially as regards that large portion of the city outsid the white-way district, where questions of economy and efficiency ar paramount, has been the subject of much controversy. There are today five types of reflecting equipment in use for street lighting: (1) the flat reflector without diffusing globe (Fig. 128), (2) the airplane-type reflector for sodium-vapor lamps (Fig. 55, II), (3) the enclosing diffusing globe (Fig. 127, I), (4) the prismatic refractor enclosing or partially enclosing the light source (Fig. 129, I), and (5) the prismatic refractor within a globe of stippled or pebbled glass which produces a slight breaking up of parallel rays of light without greatly altering their direction (Fig. 127, II). Distribution curves of the three last-named types of units equipped with a (10,000-lumen) Mazda C lamp are shown in Fig. 129.

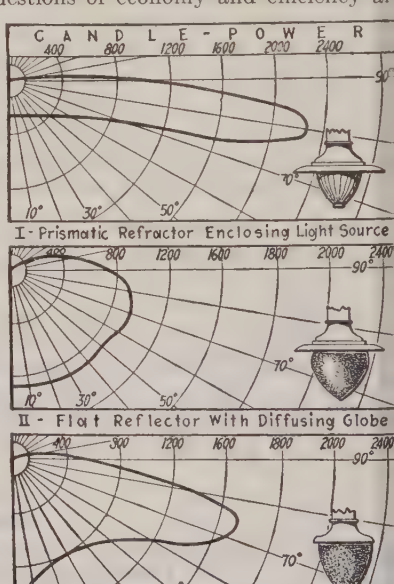


FIG. 129.—Graphs of candle-powe distribution of typical street-lightin units.

228. In locating single light units along the curb (see Fig. 130), the best results are obtained by allowing the lamps to hang from to 1½ ft. outside the curb line. In the case of single-line lighting, distance of from 3 to 5 ft. outside the curb line is usually desirable Lighting units may also be placed over the center of the street, either b suspension or on ornamental standards placed on "islands of safety. Some typical pole mountings for highway lighting are illustrated in Fig 130.

Where lamps are installed on streets bordered with trees great car should be employed to avoid the casting of heavy shadows by the foliage With upright ornamental units the lamps should always be hung a trifl lower than the lower branches of the trees if possible. If they are not heavy shadows will be cast by the branches and the effectiveness of th illumination will be greatly impaired. Usually better results can b

obtained by the use of bracket units with a mounting height of 16 ft. or more. The use of bracket units will generally result in less foliage interference.

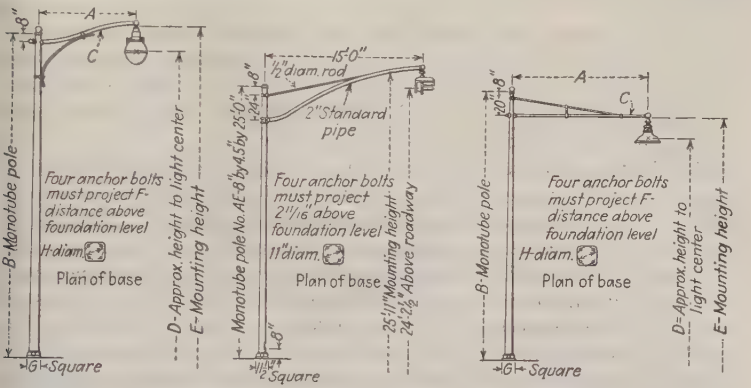


FIG. 130.—Pole mountings for highway lighting. (*General Electric Co.*)

In locating lamps along curved roadways it is often considered preferable to place them as suggested in Fig. 131 rather than all on the same side of the road. When judiciously arranged as in the manner shown the visibility is greatly increased, owing to the silhouette effect and shadows produced. Its chief objection is that the sidewalk is, in places, poorly lighted. In crossing from one side of the road to the other in the location of the units at curves, it is best to locate a pair of units opposite each other, as in Fig. 131. This will avoid confusion in determining the direction of the road. In the illumination of boulevards with sharp curves it is not good practice to stagger the location of units, as such an arrangement does not indicate well the direction of the road.

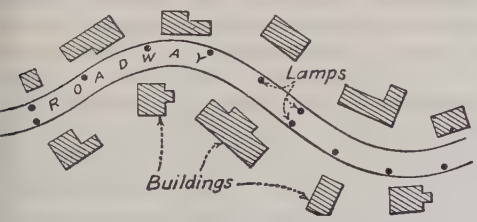


FIG. 131.—Preferable method of locating lighting units along a curved roadway.

FLOODLIGHTING

229. Modern floodlighting (General Electric Co.) meets many utilitarian requirements as well as many applications concerned with decoration, aesthetics, or advertising value. Protecting property after nightfall,

completing a construction job within the time allotted, illuminating a dangerous traffic intersection, and prolonging the hours of play on recreational areas are only a few of the almost infinite applications of utilitarian floodlighting.

As an advertising medium that compels attention without detracting from the beauty or dignity of a building, floodlighting offers its best proof by the many excellent examples to be found in almost every city. The natural beauty of churches, civic buildings, monuments, and gardens is often enhanced by skillfully applied floodlighting.

230. Lighting Effects and Location of Projectors (General Electric Co.).—The lighting effect to be obtained is generally dictated by available projector locations, architectural conformation and detail, type of business or institution, surroundings, and similar considerations. As the design of a new building evolves, however, the architect may well treat night illumination not as an afterconsideration but as an integral part of the final appearance of the building—which is coming to be considered as important by night as by day. Thus the lighting effect desired dictates the provision of suitable projector locations instead of the available projector locations dictating the lighting effect.

Small buildings of simple architectural treatment are generally most effective when floodlighted with uniform illumination by projectors placed on curb posts or on buildings not more than 200 ft. away. This method of over-all illumination, free from shadows, tends to bring out the solidity, strength, and mass of the building.

Larger buildings and skyscrapers with setback features and towers offer floodlighting the opportunity to increase their apparent height and grace and to emphasize distinctive architectural features by tasteful use of shadow effects, and color if appropriate. The projectors are usually placed immediately inside and below the parapet of ledges formed by setbacks. In cases involving floodlighting of architectural or sculptural detail, the architect's viewpoint should govern.

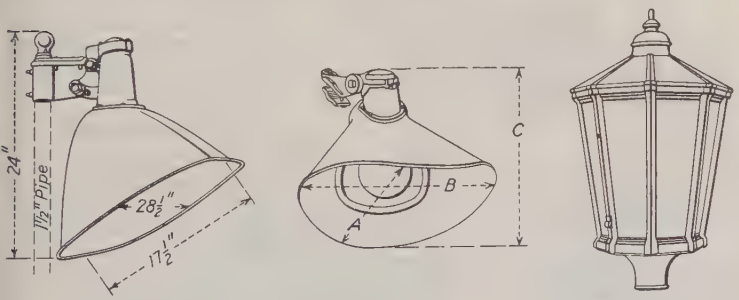
Floodlighting of construction or recreation areas is chiefly a problem of providing light for seeing, and the location of floodlighting projectors should be critically studied to eliminate glare resulting from a direct view of bright light sources in the usual field of vision.

231. Color (General Electric Co.).—Floodlighting with color adds to ordinary exterior lighting the increased effectiveness of brilliant colors and subtle pastel shades. Attention-compelling, high in advertising value, and aesthetically pleasing, color has been found to be a useful ally in floodlighting.

By the simple expedient of changing the colored cover glasses or filters on the projectors, a new artistry is introduced for the enhancement of buildings and monuments, fountains and gardens. Recently developed gaseous-discharge light sources are inherently colored and consequently produce colored light many times more efficiently than by

methods of absorption necessary with incandescent lamps. Although the use of gaseous-discharge lamps for floodlighting is not yet widespread, their higher efficiency as a source of colored light indicates more extensive use of colored floodlighting in the future.

Floodlighting reaches its apex in beauty and effectiveness with the application of mobile color lighting. The idea of color that continually changes the aspect of buildings and fountains achieved almost immediate acceptance at its introduction, and a variety of excellent examples of this treatment are in service. The display of animated color attracts the attention and approval of everyone. With Thyratron-reactor control, mobile color lighting becomes completely automatic. The striking beauty of many different color combinations can be obtained economically and can be accurately repeated in ever-changing procession without the use of cumbersome mechanical devices.



I- Open type II- Open elliptical type III- Ornamental unit

Fig. 132.—Floodlighting units.

232. Reflectors for floodlighting may be of the open type (Fig. 132, I and II), the ornamental type (Fig. 132, III), or the enclosing type (Fig. 133). The open type is commonly used for the floodlighting of games, such as baseball, tennis, etc., and for utility areas such as gas stations, parking spaces, etc. The ornamental unit is used mainly for floodlighting of buildings in city installations. The units are mounted on poles located near the sidewalks. This unit harmonizes with the street lighting, and the average person would not notice that it is being used for lighting the building instead of lighting the street. The enclosing type is used for floodlighting of buildings, when units, which direct the light upward, are mounted in niches or parapets or behind shrubs on the ground. The enclosing type is also used for sports such as baseball and football, where the units are located a long distance from the field.

233. Floodlights should be located so that they do not produce undue glare and so that they are relatively inconspicuous to the players and spectators.

234. Design of Floodlighting Installations (General Electric Co.).—The design of a floodlighting installation is the summation of a grea variety of widely varying factors, each of which bears an importan influence upon the resultant effect. The experience of the floodlightin engineer, the effect demanded by the architect, and the numerous uses floodlighting for many different buildings and lighted surfaces are only few of these factors.

Although it is true that much of floodlighting practice can be reduce to factual data, the experience of those designing the installation will d

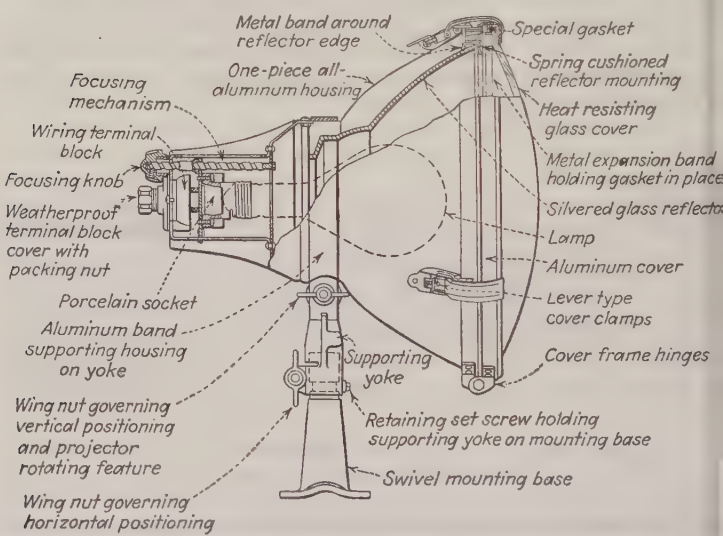


FIG. 133.—Detail of enclosed floodlight. (*General Electric Co.*)

a great deal to determine the final result. A few hours spent expe menting with various floodlighting projectors on different surfaces varying distances is of great value in this connection.

Because of the relatively few hours they are operated per season, it economical to operate floodlight lamps at about 10 per cent over th rated voltage (see Sec. **84**). The gain in lamp efficiency thus obtain provides for a saving of about 25 per cent in the number of floodligh and about 14 per cent in the amount of power used. Lamp life is reduc to about 30 per cent of normal but on the average will be sufficient f two seasons' operation or longer.

The following tables and suggestions are intended as a condens general outline of current floodlighting technique and should be us only as a guide.

235. Foot-candle Recommendations for Floodlighting Applications

(General Electric Co.)

Buildings and Monuments

Representative building materials	Approx. reflection factors, per cent	Foot-candles for downtown[a] buildings in cities of		
		Over 50,000	50,000 to 5,000	Under 5,000
White terra cotta	75	15	10	5
Cream terra cotta				
Light marble				
Light gray limestone	50	20	15	10
Bedford limestone				
Buff limestone				
Smooth buff face brick				
Briar hill sandstone	35	30	20	15
Smooth gray brick				
Medium-gray limestone				
Common tan brick				
Dark field-gray brick	20	50	30	20
Common red brick				
Brownstone				

Utilitarian and Protective Purposes

Service	Ft.-c.	Service	Ft.-c.
Construction work	5	Parking spaces	1
Dredging	2	Protective industrial	0.2
Gasoline service stations:		Quarries	2
Buildings and pumps	20	Shipyards (construction)	5
Yard and driveways	5		

Special Applications

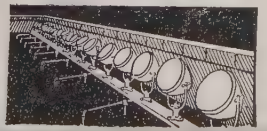
Trees	5–20	Smokestacks	15
Flags	30	Art-glass windows	20–200
Loading docks	5	Waterfalls	10
Loading platforms	5	Water tanks	15
Signs	30		

NOTE.—Buildings composed of material having a reflection factor much below 20 per cent cannot economically be floodlighted unless there is a large amount of light trim.

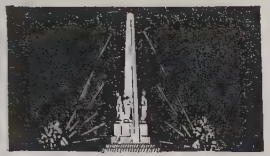
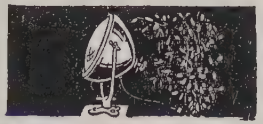
[a] For buildings in outlying districts use the foot-candles recommended for downtown buildings in cities of the next smaller classification.

236. A Guide to the Selection and Location of Floodlighting Equipment

(General Electric Co.)

Representative floodlighting applications	Typical projectors	Distance of projector from lighted surface		Beam spread of projector	Type of lamp
Buildings two or three stories high lighted from posts at curb.	Floodlights may be placed on curbposts or wide marquees to light small stores, theatres, etc., when suitable positions across the street are not available.	10- 30 ft.		Wide	General service
Buildings lighted from across street or some distance away.	When length of building face to be illuminated is not greater than distance of floodlights from building, the units can be placed in one group.	50–100 ft.	Lighted surface less than 3,000 sq. ft.	Medium	General service
			more than 3,000 sq. ft.	Wide	General service
		100–150 ft.	less than 3,000 sq. ft.	Narrow	Floodlighting
			more than 3,000 sq. ft.	Medium	General service
		150–300 ft.	less than 10,000 sq. ft.	Narrow	Floodlighting
			more than 10,000 sq. ft.	Medium	General service
Buildings of setback type.	 Units are placed immediately inside and below parapet and elevated	Height of setback	One-story	Wide	General service
			Two-story	Medium	General service
			Three-story	Medium	General service
			Four-story or more	Narrow	Floodlighting

A Guide to the Selection and Location of Floodlighting Equipment (*Continued*)

Representative floodlighting applications	Typical projectors	Distance of projector from lighted surface	Beam spread of projector	Type of lamp
 Columns, monuments.	 Best projector locations are most satisfactorily determined by trial. Statues usually require light from above to avoid grotesque effect upon human features caused by light from below.	2–100 ft.	Narrow	Floodlighting
Small outdoor areas, gas stations, driveway approaches.	Units should be mounted not less than 20 ft. high and located where they will not hinder traffic or cause accidents due to glare.	At edge of area	Wide	General service
Large outdoor areas, parking lots, etc.	To insure that glaring light sources will not be in the direct line of vision, it is advisable to mount projectors as high as possible.	At edge of area	Wide or medium (depending on length of throw)	General service

237. Number of Projectors.—Use the following formula to determine the number of projectors which will produce the required level of illumination—

$$\text{Number of projectors} = \frac{\text{area in sq. ft.} \times \text{ft.-c.}}{0.7 \times \text{beam lumens}} \qquad (14)$$

where area = area of surface to be lighted, in square feet; ft.-c. = foot-candles from Table 235; 0.7 = the *maintenance factor* and represents an allowance of 30 per cent for depreciation in service; and beam lumens = a figure to be obtained from manufacturers' catalogues for the specific equipment under consideration.

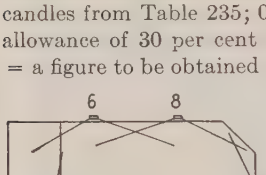


FIG. 134.—Location of poles for floodlighting a baseball diamond. (*General Electric Co.*)

238. For floodlighting a baseball diamond the location of poles is shown in Fig. 134. These fields generally use the open-type reflectors. Major-league fields and class AA fields require a much higher illumination and better control of light. For these fields floodlighting projectors or a combination of floodlighting projectors and open-type reflectors are used. When this combination is used, about 25 per cent of the load is required in floodlighting projectors, the majority of which are placed on poles 1, 2, 3, and 4 with only a few on the other poles to light the short center field. Table 239 gives the approximate total rated kilowatts of lights and their mounting height for five classes of field. The proper distribution of the load between the various poles of Fig. 134 is shown also.

239. Load Required and Mounting Height for Baseball Floodlighting

(General Electric Co.)

Class	Kw. load at normal voltage	Mounting height, ft.
Major league	750–1,000	Open units, 100 min. Closed units, 120 min.
AA	400– 600	Open units, 100 min. Closed units, 120 min.
A and B	200– 350	80–90
C and D	175– 250	70–80
Semipro	150– 170	60–70

239A. Distribution of Load between Poles

Pole location	Per cent of load per pole
1 and 2	8¼
3 and 4	16⅔
5, 6, 7, 8	12½

240. For floodlighting a football field (Fig. 135) open-type reflectors are used when they are located between the stands and the field, and

enclosed projectors when they are located behind the stands. The size of the audience and the skill of the players determine the number of units.

1. For high schools and small colleges three to five poles are erected on each side of field, 75 ft. apart, about 45 ft. high and approximately 15 ft. from the side lines. Five to six kilowatts on each pole is minimum for small schools, six to twelve kilowatts for larger schools.

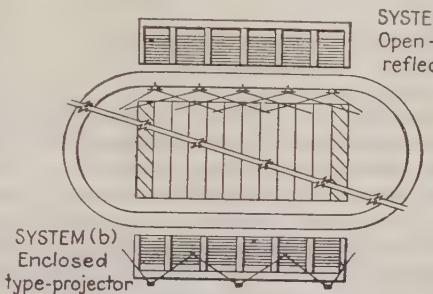


FIG. 135.—Two systems for locating floodlights for a football stadium. (*General Electric Co.*)

2. For medium-sized stadiums, six towers, three on each side, are mounted behind or in back of the stadium, 70 to 90 ft. above the playing field. The towers are spaced about 150 ft. apart with 12 to 20 1,000-watt floodlight projectors per tower.

241. For floodlighting of race tracks (General Electric Co.), 16-ft. mast arms equipped with two 750-watt R.L.M. domes (Fig. 136) are

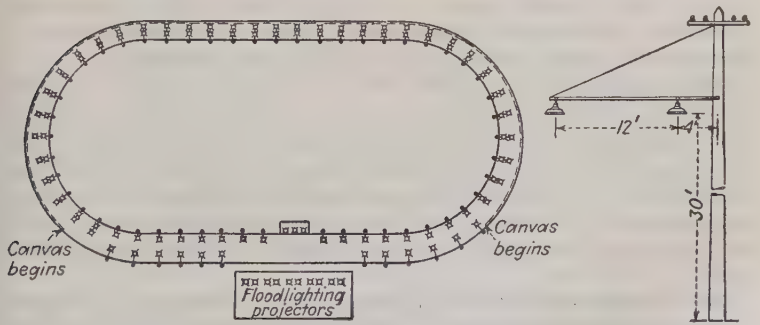


FIG. 136.—Location of lights for floodlighting a race track. (*General Electric Co.*)

located on the inside of the track. On the home stretch use two rows of single 1,500-watt units, one on inside, one on outside of track. On curves and backstretch, two units per mast arm are placed 4 and 16 ft. out from pole. White canvas on fence is commonly used in this area to silhouette horses so that they are easily visible from the grandstand. Floodlight projectors may be placed on the grandstand if needed to light the track

in front of the grandstand, where poles would obstruct view. Recommended spacing is 50 ft.

242. Archery (General Electric Co.).—This increasingly popular sport requires sufficient light not only to illuminate the target satisfactorily but also to light the area surrounding the target. Targets are usually spaced about 10 yd. apart for safety.

Type of projector: one narrow beam for each target. *Location:* directly behind and to left of archer, mounted 10 ft. high. *Lamp size:* 250-watt for average ranges, 500-watt for longer range.

243. Badminton (General Electric Co.).—Because of the high flight of the bird, the lighting arrangement must avoid overbright light sources in the players' eyes while looking upward. Uneven levels of illumination will cause the bird to appear to hop or change speed in flight.

INDOOR.—*Type of unit:* 24-in. glassteel. *Location:* three units, 25 ft. high, at each end of net. *Lamp size:* 750-watt. *Foot-candles recommended:* 25.

OUTDOOR.—*Type of reflector:* open type, mat porcelain enamel. *Location:* two reflectors at each end of net on 29-ft. poles. *Lamp size:* 750- or 1,000-watt. *Foot-candles recommended:* 25.

244. Bathing Beaches (General Electric Co.).—The swimming area as well as the beach should be illuminated. The size and type of beach determine projector locations, direction of beam, etc.

Type of projector: banks of narrow-beam, floodlighting projectors. *Location:* 200 to 400 ft. apart, mounted 40 to 80 ft. high. *Lamp size:* 1,000-watt. *Foot-candles recommended:* sufficient projectors located in each bank to provide approximately 1 ft.-c. evenly distributed.

245. Billiards (General Electric Co.).—*Type and location of reflectors:* (1) Three 100-watt deep-bowl porcelain or parchment reflectors spaced 3 ft. apart along center line of table, mounted 5 ft. above floor. (2) Where unobstructed view throughout room is desirable, a trough-type housing with lens plates or aluminum parabolic reflectors with silvered-bowl lamps may be used. Four 100- or 150-watt lamps spaced 1½ ft. apart will give good concentration of light at mounting heights up to 10 ft.

246. Bowling Alleys (General Electric Co.).—Bowling alleys require good uniformity of illumination along each alley, with light sources well shielded from players. Additional supplementary floodlighting should be provided directly on the pins, usually supplied by a 200-watt projector mounted above and a little ahead of the pins.

Type of reflector: angle type. *Location:* 9 ft. apart on center line of each alley and about 10 ft. above alley. *Lamp size:* 150-watt. *Foot-candles:* on alley, 10; on pins, 25.

247. Bowling on the Green (126 by 126 ft.) (General Electric Co.).—The court should be fairly uniformly lighted to about 5 ft.-c. and from a sufficient number of sources so as to minimize long sweeping shadows.

SIDE LIGHTING.—*Type of reflector:* elliptical angle. *Location:* 21 ft. from the ends, 42 ft. apart on each of the four sides, and 5 ft. or more outside the boundaries of the green. *Lamp size:* 1,000- or 1,500-watt. *Mounting height:* 25 ft.

248. Boxing (General Electric Co.).—The level of illumination required for boxing is dictated by such considerations as the size of the audience, importance of bout, and whether or not motion pictures are to be taken.

CHAMPIONSHIP.—*Type of reflector:* open concentrating. *Location:* 20 units, 18 ft. above the ring on poles outside the corners. *Lamp size:* 1,000-watt.

AVERAGE BOUTS.—Eight or twelve 1,000-watt units, according to the bout's importance.

249. Croquet or Roque (30 by 60 ft.) (General Electric Co.).—Good lighting must be uniform and free from shadows for the accurate execution of difficult shots. Five foot-candles is recommended.

SIDE LIGHTING.—*Type of reflector:* open-type angle. *Location:* 12 ft. from the end of the court, 36 ft. apart, and mounted on four 20-ft. poles. *Lamp size:* 750- to 1,500-watt.

OVERHEAD LIGHTING.—*Type of reflector:* R.L.M. domes. *Location:* strung on messenger cables 25 ft. above the court on 15-ft. center. *Lamp size:* 300-watt.

250. Golf Driving Range (General Electric Co.).—Short high shots as well as long, powerful drives must be illuminated so that players may follow the ball throughout its flight.

Types of projectors: (1) High candle power, narrow angle for long drives, (2) medium angle for short high shots. *Location:* two projectors for each tee with no less than a total of nine projectors for any driving range located on poles 20 ft. behind the tee, 25 ft. apart. About one-fourth of the units should be medium-angle projectors. *Mounting height:* approximately 30 ft. *Lamp size:* 1,000- or 1,500-watt.

251. Hockey (Outdoor) (General Electric Co.).—The units should be located just outside the rink to prevent slush and water from dripping on the ice and causing rough spots.

Type of projector: two floodlighting projectors or open-type reflectors per pole. *Location:* mounted 35 ft. high and spaced about 50 ft. apart. *Lamp size:* 1,000- or 1,500-watt. *Foot-candles recommended:* 10.

252. Horseshoe Courts (General Electric Co.).—1. FOR ONE TO THREE COURTS.—*Type of reflector:* elliptical angle. *Location:* on two 20-ft. poles placed 6 ft. outside the stake enclosure at diagonally opposite corners. *Lamp size:* one 750-watt on each pole.

2. FOR FOUR TO EIGHT COURTS.—Use four 750-watt lamps, one on each of four poles located as above outside each corner of the field.

253. Skeet (General Electric Co.).—In skeet, the flight of the clay pigeons is intended to duplicate the angles of flight found in actual wing shooting. Projector beams are crossed to eliminate distorting shadows.

Type of projector: medium-angle, 40 deg. spread lens. *Location:* about 25 ft. back of shooting line at a height of 20 to 25 ft. *Lamp size:* 1,000-watt. Use 6 to 10 divided between two poles.

Above each shooter's stand, except at station 8, place one 100-watt lamp in an R.L.M. Dome to facilitate loading and aiming.

254. Swimming Pool (General Electric Co.).—For Surface Lighting Equipment.—Two open-type floodlighting projectors, or two enclosed projectors with heavily stippled clear-glass doors. *Location:* at each corner of the pool runway on 20- to 30-ft. poles. *Lamp size:* 1,000- or 1,500-watt.

Underwater Lighting.—The water must be sufficiently clear so that the bottom 10 ft. below the surface may be seen in daylight. Two classes of underwater lighting are:

1. *Dry Niche.*—500- or 1,000-watt projector with 40-deg. spread lenses, spaced not more than 12 ft. apart on each side of pool 1 to 1½ ft. below the water level. Manhole to be provided for servicing. Use 1 to 3 watts per sq. ft. of pool area for outdoor pools; 2½ to 5 watts per sq. ft. for indoor pools.

2. *Wet Niche.*—Same as above except that 250- to 1,500-watt underwater equipment is necessary. Units are mounted 1 to 1½ ft. below water level. Front of niche should be protected by bull mesh. Because of the flexible hose and conductor, this type of wet-niche unit makes possible cleaning or replacement of lamps without draining pool.

255. Table Tennis (General Electric Co.).—Lighting requirements are simple, but for full enjoyment of the game, 30 or 40 ft.-c. are needed in order to follow the small white ball in its speedy back-and-forth motion.

Type of reflector: special parchment shades with large shielding angle. *Location:* 3 to 7 ft. above table. *Lamp size:* 150-watt.

256. Tennis (Outdoor) (General Electric Co.).—For full enjoyment the light sources must be well shielded, and illumination of the order of 20 to 30 ft.-c. should be provided.

Single or Double Courts.—*Type of reflector:* wide angle, deep bowl, aluminum with skirt. *Location:* mounted 30 ft. high on brackets from poles. *Lamp size:* 1,000- or 1,500-watt. Use 8 for recreational play; 16 for championship.

Three or Four Courts.—Add 4 or 8 units, respectively.

257. Trapshooting (General Electric Co.).—Floodlighting stations are placed on either side of shooting platform. The beams from each station are crossed to eliminate shadows. Stray light on platforms is sufficient to sight guns and to facilitate changing positions.

Type of projector: eight medium-beam floodlighting projectors. *Location:* two poles (four projectors per pole) mounted 20 to 25 ft. high behind shooting platform. *Lamp size:* 1,000-watt.

DIVISION 11

WIRING TABLES

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1. Standard Sizes of Lamps, in Watts

Incandescent		Fluorescent	Mercury Mazda
		6	
		8	
10	150	13	
15	200	14	
25		15	250
40	300	20	400
50	500	30	1,000
	750	40	3,000
60	1,000	100	
75	1,500		
100			

2. Demand Loads for Household Electric Ranges and Other Cooking Appliances Over 1¾-kw. Rating

Column *A* to Be Used in All Cases Except as Otherwise Permitted in Note 3 Belo

Number of ranges	Maximum demand, kw. (see Notes)	Demand factors (see Note 4), per cent	
	Column *A* (not over 12 kw. rating)	Column *B* (less than 3½ kw. rating)	Column *C* (3½ kw. to 8¾ kw rating)
1	8	80	80
2	11	75	65
3	14	70	55
4	17	66	50
5	20	62	45
6	21	59	43
7	22	56	40
8	23	53	36
9	24	51	35
10	25	49	34
11	26	47	32
12	27	45	32
13	28	43	32
14	29	41	32
15	30	40	32
16	31	39	28
17	32	38	28
18	33	37	28
19	34	36	28
20	35	35	28
21	36	34	26
22	37	33	26
23	38	32	26
24	39	31	26
25	40	30	26
26–30	15 kw. plus 1 kw. for each range	30	24
31–40		30	22
41–50	25 kw. plus ¾ kw. for each range	30	20
51–60		30	18
61 and over		30	16

NOTE 1.—**Over-12-kw. to 21-kw. ranges all of the same rating.** For ranges ind vidually rated more than 12 kw. but not more than 21 kw., the maximum demand i Column *A* shall be increased 5 per cent for each additional kw. of rating or maj fraction thereof by which the rating of individual ranges exceeds 12 kw.

NOTE 2.—**Over-12-kw. to 21-kw. ranges of unequal rating.** For ranges individuall rated more than 12 kw. and of different ratings but none exceeding 21 kw., an averag value of rating shall be calculated by adding together the ratings of all ranges to obtai the total connected load (using 12 kw. for any range rated less than 12 kw.) and dividin by the total number of ranges; and then the maximum demand in Column *A* shall b increased 5 per cent for each kilowatt or major fraction thereof by which this averag value exceeds 12 kw.

NOTE 3.—Generally the demand for commercial ranges should be based on the maximum name-plate rating.

NOTE 4.—**Over 1¾ kw. to 8¾ kw.** In lieu of the method provided in Column *A*, the load for ranges individually rated more than 1¾ kw. but not more than 8¾ kw. may be considered as the sum of the name-plate ratings of all the ranges, multiplied by the demand factors specified in Columns *B* or *C* for the given number of ranges.

NOTE 5.—**Branch-circuit load.** Branch-circuit load for one range may be computed in accordance with the above table.

3. Demand Factors for Lighting Loads

Occupancy of area	Demand factor
All dwellings (other than hotels) and apartment houses having provision for individual cooking by tenants[a]	For areas of 2,000 sq. ft. or less: 1.0 For areas greater than 2,000 sq. ft.: 1.0 for load on first 2,000 sq. ft. 0.35 for load on all area between 2,000 and 40,000 sq. ft. 0.25 for load on all area in excess of 40,000 sq. ft.
Hotels, including apartment houses without provisions for cooking by tenants	For areas of 10,000 sq. ft. or less: 0.5 For areas greater than 10,000 sq. ft.: 0.5 for load on first 10,000 sq. ft. 0.4 for load on all area in excess of 10,000 sq. ft. up to 50,000 sq. ft. 0.3 for load on all area in excess of 50,000 sq. ft.
Stores and department stores including show windows	1.0 for all areas
Office buildings	For areas of 10,000 sq. ft. or less: 1.0 For areas greater than 10,000 sq. ft.: 1.0 for load on first 10,000 sq. ft. 0.70 for load on all area in excess of 10,000 sq. ft.
Hospitals	For areas of 25,000 sq. ft. or less: 0.4 For areas greater than 25,000 sq. ft.: 0.4 for load on first 25,000 sq. ft. 0.2 for load on all area in excess of 25,000 sq. ft.
Schools	For areas of 5,000 sq. ft. or less: 1.0 For areas greater than 5,000 sq. ft.: 1.0 for load on first 5,000 sq. ft. 0.5 for load on all area in excess of 5,000 sq. ft.
Storage warehouses	For areas of 50,000 sq. ft. or less: 1.0 For areas greater than 50,000 sq. ft.: 1.0 for load on first 50,000 sq. ft. 0.5 for load on all area in excess of 50,000 sq. ft.
All other buildings including factory buildings, commercial loft buildings, garages, etc.	1.0 for all areas

[a] Any electric-cooking-range load and fixed-appliance load not to be included in applying these demand factors.

[b] In any of the above occupancies where entire lighting load is likely to be used at one time, as in assembly halls, auditoriums, halls, and corridors of public buildings, operating rooms, ballrooms, public dining rooms, etc., a demand factor of 1.0 should be used.

4. Data for Determining National Electrical Code Minimum Allowabl

Lighting and Appliance Loads

Minimum Allowable General-lighting Loads

Type of occupancy	Column *A* unit load per sq. ft. (watts)	Column *B* Load to which demand factor applies (watts)	Column *B* Demand factor, per cent
Armories and auditoriums	1	Total wattage	100
Banks	2	Total wattage	100
Barber shops and beauty parlors	3	Total wattage	100
Churches	1	Total wattage	100
Clubs	2	Total wattage	100
Courtrooms	2	Total wattage	100
Dwellings (other than hotels)	3	3,000 or less	100
		Next 117,000	35
		Over 120,000	25
Garages—commercial (storage)	½	Total wattage	100
Hospitals	2	50,000 or less	40[a]
		Over 50,000	20
Hotels, including apartment houses without provisions for cooking by tenants	2	20,000 or less	50[a]
		Next 80,000	40
		Over 100,000	30
Industrial commercial (loft) buildings	2	Total wattage	100
Lodge rooms	1½	Total wattage	100
Office buildings	2	20,000 or less	100
		Over 20,000	70
Restaurants	2	Total wattage	100
Schools	3	15,000 or less	100
		Over 15,000	50
Stores	3	Total wattage	100
Warehouses, storage	¼	12,500 or less	100
		Over 12,500	50
In any of above occupancies except single-family dwellings and individual apartments of multifamily dwellings:			
Assembly halls and auditoriums	1	Total wattage as specifie	
Halls, corridors, closets	½	for the specific occupanc	
Storage spaces	¼		

[a] For subfeeders to areas in hospitals and hotels where entire lighting is likely to b used at one time; as in operating rooms, ballrooms, dining rooms, etc., a demand facto of 100 per cent shall be used.

Minimum Allowable Appliance Loads

1. In dwelling occupancies the small-appliance load for all rooms except kitchen, laundry, pantry, dining room, and breakfast room, ma be considered as a part of the general lighting load, and no additiona load need be included for these appliances.

2. In dwelling occupancies a load of at least 1,500 watts must be adde to the general lighting load for small appliances used in kitchen, laundry pantry, dining room, and breakfast room.

3. In other than dwelling occupancies, load for appliances or lighting other than general illumination must be included for the specific loads to be served, but a load not less than specified below must be included for each outlet:

Outlets supplying fixed appliances or special appliances... Ampere rating of appliance
Outlets supplying heavy-duty lamp holders..... 5 amp.
Other outlets except multioutlet assemblies..... 1½ amp.

4. In all occupancies load must be included for all fixed appliances in accordance with the ratings of the appliances. Where four or more fixed appliances, in addition to an electric range or ranges, are connected to the same feeder in a single or multifamily dwelling, a demand factor of 75 per cent may be applied to the fixed-appliance load, not including the electric ranges.

5. **Show-window Lighting.**—For show-window lighting a load of not less than 200 watts for each linear foot of show window, measured horizontally along its base, may be allowed in lieu of the specified load per outlet.

6. **Multioutlet Assemblies.**—Where fixed multioutlet assemblies are employed, each 5 ft. or fraction thereof of each separate and continuous length shall be considered as one outlet of not less than 1½ amp. capacity; except in locations where a number of appliances are likely to be used simultaneously, when each 1 ft. or fraction thereof shall be considered as an outlet of not less than 1½ amp.

5. Average Demand Factors for Motor Loads[a]

Number of motors	Character of load	Demand factor
1– 5	Individual drives—tools, etc.	1.00
6– 10	Individual drives—tools, etc.	0.75
10– 15	Individual drives—tools, etc.	0.70
15– 20	Individual drives—tools, etc.	0.65
20– 30	Individual drives—tools, etc.	0.60
30– 50	Individual drives—tools, etc.	0.50
50– 75	Individual drives—tools, etc.	0.45
75–100	Individual drives—tools, etc.	0.40
Above 100	Individual drives—tools, etc.	0.40
6– 10	Group drives	0.85
Above 10	Group drives	0.70–0.45
	Fans, compressors, pumps, etc.	1.00–0.85

[a] Permission for the use of a demand factor should be obtained from the authority enforcing the National Electrical Code.

6. Average Full-load Currents of D-c Motors[a]

Hp.	115 volts	230 volts	550 volts	Hp.	115 volts	230 volts	550 vol
	Full-load current amp.				Full-load current, amp.		
½	4.6	2.3		20	148	74	31
¾	6.6	3.3	1.4	25	184	92	38
1	8.6	4.3	1.8	30	220	110	46
1½	12.6	6.3	2.6	40	292	146	61
2	16.4	8.2	3.4	50	360	180	75
3	24.0	12.0	5.0	60	430	215	90
5	40	20	8.3	75	536	268	111
7½	58	29	12.0	100	...	355	148
10	76	38	16.0	125	...	443	184
15	112	56	23.0	150	...	534	220
				200	...	712	295

7. Average Full-load Currents of Single-phase Motors[a,b]

Hp.	115 volts	230 volts	440 volts	Hp.	115 volts	230 volts	440 vo
	Full-load current, amp.				Full-load current, amp.		
⅙	3.2	1.6		1½	18.4	9.2	
¼	4.6	2.3		2	24	12	
½	7.4	3.7		3	34	17	
¾	10.2	5.1		5	56	28	
1	13	6.5		7½	80	40	21
				10	100	50	26

[a] These values of full-load current are for motors running at speeds usual for bel motors and motors with normal torque characteristics. Motors built for especi low speeds or high torques may require more running current, in which case the na plate current rating should be used.

[b] For full-load currents of 208- and 200-volt motors, increase corresponding 220- motor full-load current by 10 and 15 per cent, respectively.

8. Average Full-load Currents of Two-phase Motors

Hp.	Full-load currents for squirrel-cage and wound-rotor induction types					Full-load currents for synchronous unity-power-factor type[a]			
	110 volts	220 volts	440 volts	550 volts	2,300 volts	220 volts	440 volts	550 volts	2,300 volts
½	4	2	1	0.8					
¾	4.8	2.4	1.2	1.0					
1	6.4	3.2	1.6	1.3					
1½	8.8	4.4	2.2	1.8					
2	11.2	5.6	2.8	2.2					
3	....	8	4	3.2					
5	....	13	7	6					
7½	....	19	9	8					
10	....	24	12	10					
15	....	34	17	14					
20	....	45	23	18					
25	....	55	28	22	6	47	24	19	4.7
30	....	67	34	27	7.5	56	29	23	5.7
40	....	88	44	35	9	75	37	31	7
50	....	108	54	43	11	94	47	38	9
60	....	129	65	52	13	111	56	44	11
75	....	158	79	63	16	140	70	57	13
00	....	212	106	85	21	182	93	74	17
25	....	268	134	108	26	228	114	93	22
50	....	311	155	124	31	...	137	110	26
00	....	415	208	166	41	...	182	145	35

For 90 and 80 per cent p. f., the above figures should be multiplied by 1.1 and 1.25, pectively.

Values given are those for each wire of a four-wire system and for the tside wires of a three-wire system. The current in the common wire a three-wire system will be 1.41 times the values given.

These values of full-load currents are for motors running at speeds ual for belted motors and motors with normal torque characteristics. otors built for especially low speeds or high torques may require more ning current, in which case the name-plate current rating should be ed.

9. Average Full-load Currents of Three-phase Motors[a]

Hp.	Full-load currents for squirrel-cage and wound-rotor induction types					Full-load currents for synchro nous unity-power-factor type			
	110 volts	220 volts	440 volts	550 volts	2,300 volts	220 volts	440 volts	550 volts	2,30 volt
½	4	2	1	0.8					
¾	5.6	2.8	1.4	1.1					
1	7	3.5	1.8	1.4					
1½	10	5	2.5	2.0					
2	13	6.5	3.3	2.6					
3	....	9	4.5	4					
5	....	15	7.5	6					
7½	....	22	11	9					
10	....	27	14	11					
15	....	40	20	16					
20	....	52	26	21					
25	....	64	32	26	7	54	27	22	5
30	....	78	39	31	8.5	65	33	26	6
40	....	104	52	41	10.5	86	43	35	8
50	....	125	63	50	13	108	54	44	10
60	....	150	75	60	16	128	64	51	12
75	....	185	93	74	19	161	81	65	15
100	....	246	123	98	25	211	106	85	20
125	....	310	155	124	31	264	132	106	25
150	....	360	180	144	37	...	158	127	30
200	....	480	240	192	48	...	210	168	40

[a] These values of full-load current are for motors running at speeds usual for bel motors and motors with normal torque characteristics. Motors built for especially l speeds or high torques may require more running current, in which case the name-pl current rating should be used.

[b] For 90 and 80 per cent p. f., the above figures should be multiplied by 1.1 and 1. respectively.

For full-load currents of 208- and 200-volt motors, increase t corresponding 220-volt-motor, full-load current by 6 and 10 per ce respectively.

10. Minimum Current-carrying Capacity for Conductors Supplying Motors Used for Short-time, Intermittent, Periodic, or Varying Duty

Classification of service	5-min. rating	15-min. rating	30- and 60-min. rating	Continuous rating
	Percentage[a] of name-plate current rating			
Short-time duty:				
Operating valves, raising or lowering rolls....	110	120	150	
Intermittent duty:				
Freight and passenger elevators, shop cranes, tool heads, pumps, drawbridges, turntables, etc.....	85	85	90	140
Periodic duty:				
Hoists, rolls, ore- and coal-handling machines.	85	90	95	140
Varying duty.....	110[a]	120[a]	150[a]	200[a]

[a] Or lower, at the discretion of the authorities enforcing the regulations.

10A. Carrying Capacities of Wires between Secondary Controller of Wound-rotor Induction Motors and Resistors

Resistor Duty Classification (N.E.M.A. Apparatus Division)	Carrying Capacity of Wire, Per Cent of Full-load Secondary Current
Light starting duty.....	35
Heavy starting duty.....	45
Extra-heavy starting duty.....	55
Light intermittent duty.....	65
Medium intermittent duty.....	75
Heavy intermittent duty.....	85
Continuous duty.....	110

11. Current-carrying Capacities of Conductors Having Rubber or Thermoplastic Insulation Which Supply Crane and Hoist Motors in Amp[a]

Size, A.w.g. or cir. mils	For motors having 30- and 60-min. short-time ratings	For motors having 5- and 15-min. short-time ratings
16	10	11
14	20	22
12	25	28
10	35	39
8	45	50
6	57	63
5	65	72
4	77	85
3	90	99
2	107	118
1	130	143
1/0	160	176
2/0	195	215
3/0	245	270
4/0	300	330
250,000	350	385
300,000	410	450
350,000	460	510
400,000	515	570
450,000	565	620
500,000	620	680

[a] For other insulated conductors use values in Tables 18 and 18A increased b 10 per cent.

Conductors shall not be smaller than No. 14 except:

1. On small cranes and hoists, No. 16 may be used provided the co ductors are protected against mechanical injury.

2. On operating circuits No. 16 may be used provided the conducto are protected against mechanical injury.

Contact Conductors.—The size of contact wires shall be not less tha the following:

Distance between End Strain Insulators, Ft.	Size of Wire
0–30	No. 6
31–60	No. 4
Over 60	No. 2

12. The National Electrical Manufacturers' Association has adopted a standard of identifying code letters that may be marked by the manufacturer on motor name plates to show the motor kilovolt-ampere input with locked rotor. The meaning of the code letters is as follows:

Code Letter	Kva. per Hp. with Locked Rotor	Code Letter	Kva. per Hp. with Locked Rotor
A	0 –3.14	*L*	9.0– 9.99
B	3.15–3.54	*M*	10.0–11.19
C	3.55–3.99	*N*	11.2–12.49
D	4.0– 4.49	*P*	12.5–13.99
E	4.5 –4.99	*R*	14.0–15.99
F	5.0 –5.59	*S*	16.0–17.99
G	5.6 –6.29	*T*	18.0–19.99
H	6.3 –7.09	*U*	20.0–22.39
J	7.1 –7.99	*V*	22.4 and up
K	8.0 –8.99		

3. Maximum Rating or Setting of Motor-branch-circuit Protective Devices for Motors Marked with a Code Letter Indicating Locked-rotor Kilovolt-amperes

(Average Starting Currents)

Type of motor	Fuse rating	Circuit-breaker setting	
		Instantaneous type	Time-limit type
	Per cent of full-load current		
All a-c, single-phase and polyphase, squirrel-cage, and synchronous motors with full-voltage, resistor or reactor starting:		Not allowed by Code	
Code letter *A*	150		150
Code letter *B* to *E*	250		200
Code letter *F* to *V*	300		250
All a-c, squirrel-cage, and synchronous motors with autotransformer starting:			
Code letter *A*	150		150
Code letter *B* to *E*	200		200
Code letter *F* to *V*	250		200

For certain exceptions to the values specified see Sec. **436,** Div. 7. The values given in the last column also cover the ratings of nonadjustable, time-limit types of circuit breaker.

Synchronous motors of the low-torque, low-speed type (usually 450 r.p.m. or lower), such as are used to drive reciprocating compressors, pumps, etc., which start up unloaded, do not require a fuse rating or circuit-breaker setting in excess of 200 per cent of full-load current.

For motors not marked with a Code letter, see Table 14.

14. Maximum Allowable Ratings of Fuses and Settings of Circuit Breakers for the Protection of Branch Motor Circuits for Motors Not Marked with a Code Letter Indicating Locked-rotor Kilovolt-amperes[a]

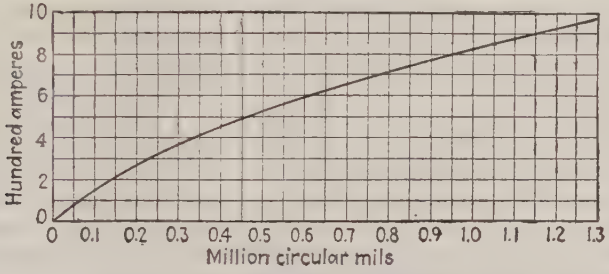
(Values are for continuous-duty motors wired with conductors having a carrying capacity of 125 per cent of the motor full-load current)

Type of motor	Fuses	Instantaneous-type circuit breaker	Time-limit-type circuit breaker
	Maximum allowable rating or setting of overload protective device in percentage of motor full-load current		
Single-phase (all types)	300	...	250
Polyphase, squirrel-cage:			
Normal-starting-current type, when started with full voltage or reduced voltage by resistor or reactor	300	...	250
Normal-starting-current type, when started with reduced voltage by autotransformer (full-load current not more than 30 amp.)	250	...	200
Normal-starting-current type, when started with reduced voltage by autotransformer (full-load current more than 30 amp.)	200	...	200
Low-starting-current types (full-load current not more than 30 amp.)	250	...	250
Low-starting-current types (full-load current more than 30 amp.)	200	...	200
High-resistance type (full-load current not more than 30 amp.)	250	...	250
High-resistance type (full-load current more than 30 amp.)	200	...	200
Automatic-start type	150	...	150
Polyphase, commutator type, brush-shifting (full-load current not more than 30 amp.)	250	...	250
Polyphase, commutator type, brush-shifting (full-load current more than 30 amp.)	200	...	200
Polyphase, polyspeed type of motor:			
Heavy-starting duty (full-load current not more than 30 amp.)	300	...	250
Heavy-starting duty (full-load current more than 30 amp.)	250	...	200
Moderate-starting duty (full-load current not more than 30 amp.)	250	...	250
Moderate-starting duty (full-load current more than 30 amp.)	200	...	200
Light-starting duty	150	...	150
Polyphase, wound rotor	150	...	150
Polyphase, synchronous—general purpose:			
High-speed type and low-speed, high-torque type when started with full voltage or reduced voltage by resistor or reactor	300	...	250
High-speed type and low-speed, high-torque type when started with reduced voltage by autotransformer (full-load current not more than 30 amp.)	250	...	200
High-speed type and low-speed, high-torque type when started with reduced voltage by autotransformer (full-load current more than 30 amp.)	200	...	200
Low-speed, low-torque type (full-load current not more than 30 amp.)	250	...	250
Low-speed, low-torque type (full-load current more than 30 amp.)	200	...	200
Fynn-Weichsel	150	...	150
Supersynchronous, when started with full voltage or reduced voltage by resistor or reactor	300	...	250
Supersynchronous, when started with reduced voltage by autotransformer	200	...	200
Direct current, not more than 50 hp. (all types)	150	250	150
Direct current, more than 50 hp. (all types)	150	175	150

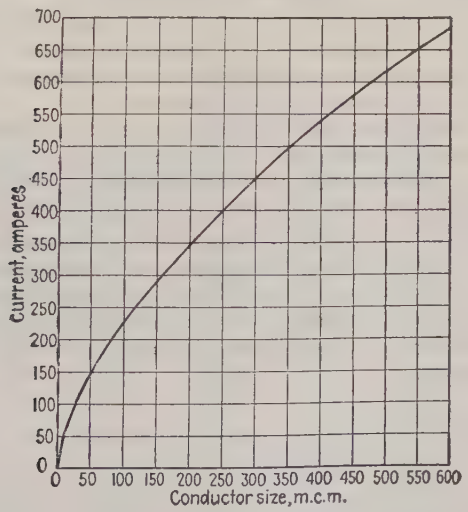
[a] For certain exceptions to the values specified see Sec. **436**, Div. 7. The values given in the last column also cover the ratings of nonadjustable, time-limit types of circuit breakers.

15. Curve for Determining Current Capacities at 60 Cycles of Bare Concentric Stranded Copper Conductors for 30°C. Rise over 40°C. Ambient

For outdoor service, 25 per cent increase in capacities is permissible.



16. Curve for Determining Current-carrying Capacity for Weatherproof Covered Concentric Stranded Copper Conductors Installed Outside Buildings



17. National Electrical Code allowable current-carrying capacities of conductors for all interior wiring.

1. **Aluminum Conductors.**—For aluminum conductors, the allowable current-carrying capacities shall be taken as 84 per cent of those given in the table for the respective sizes of copper conductor with the same kind of insulation.

2. **Bare Conductors.**—If bare conductors are used in raceways with insulated conductors, their allowable current-carrying capacity shall be

limited to that permitted for the insulated conductor with which they are used.

3. **More than Three Conductors in a Raceway.**—Table 18*A* gives the allowable current-carrying capacity for not more than three conductors in a raceway or cable. If the number of conductors in a raceway or cable is from four to six, the allowable current-carrying capacity of each conductor shall be reduced to 80 per cent of the values in Table 18*A*. If the number of conductors in a raceway or cable is from seven to nine, the allowable current-carrying capacity of each conductor shall be reduced to 70 per cent of the values in Table 18*A*.

4. **Neutral Conductor.**—A neutral conductor which carries only the unbalanced current from other conductors, as in the case of normally balanced circuits of three or more conductors, shall not be counted in determining the current-carrying capacities of Table 18*A*.

In a three-wire circuit from a four-wire, three-phase system, a common conductor carries approximately the same current as the other conductors and is not therefore considered as a neutral conductor.

5. **Ultimate Insulation Temperature.**—In no case shall conductors be associated together in such a way with respect to the kind of circuit, the wiring method employed, or the number of conductors, that the limiting temperature of the conductors will be exceeded.

6. **Use of Conductors with Higher Operating Temperatures.**—If the room temperature is within 10°C. of the maximum allowable operating temperature of the insulation, it is desirable to use an insulation with a higher maximum allowable operating temperature; although insulation can be used in a room temperature approaching its maximum allowable operating temperature limit if the current is reduced in accordance with the table of correction factors for different room temperatures.

7. **Voltage Drop.**—The allowable current-carrying capacities in Tables 18 and 18*A* are based on temperature alone and do not take voltage drop into consideration.

18. National Electrical Code Allowable Current-carrying Capacities for Conductors for Open Wiring on Insulators and for Concealed Knob and Tube Wiring

Single Conductor in Free Air[a]

[Based on Room Temperature of 30°C. (86°F.); All Current-carrying Capacities Given in Amperes]

Size, A.w.g. or cir. mils	Rubber Type R, Type RW, Type RU Type RUW (14-2) / Thermoplastic, Type T, Type TW	Rubber Type RH	Thermoplastic asbestos Type TA / Var-Cam Type V / Asbestos Var-Cam TypeAVB	Asbestos Var-Cam TypeAVA TypeAVL	Impregnated asbestos Type AI (14-8) Type AIA	Asbestos Type A (14-8) Type AA	Slow-burning Type SB / Weather-proof Type WP Type SBW
14	20	20	30	40	40	45	30
12	25	25	40	50	50	55	40
10	40	40	55	65	70	75	55
8	55	65	70	85	90	100	70
6	80	95	100	120	125	135	100
4	105	125	135	160	170	180	130
3	120	145	155	180	195	210	150
2	140	170	180	210	225	240	175
1	165	195	210	245	265	280	205
1/0	195	230	245	285	305	325	235
2/0	225	265	285	330	355	370	275
3/0	260	310	330	385	410	430	320
4/0	300	360	385	445	475	510	370
250,000	340	405	425	495	530	...	410
300,000	375	445	480	555	590	...	460
350,000	420	505	530	610	655	...	510
400,000	455	545	575	665	710	...	555
500,000	515	620	660	765	815	...	630
600,000	575	690	740	855	910	...	710
700,000	630	755	815	940	1,005	...	780
750,000	655	785	845	980	1,045	...	810
800,000	680	815	880	1,020	1,085	...	845
900,000	730	870	940	.....	.....	...	905
1,000,000	780	935	1,000	1,165	1,240	...	965
1,250,000	890	1,065	1,130				
1,500,000	980	1,175	1,260	1,450	.....	...	1,215
1,750,000	1,070	1,280	1,370				
2,000,000	1,155	1,385	1,470	1,715	.....	...	1,405

Correction Factor for Room Temperatures over 30°C. (86°F.)

°C.	°F.							
40	104	0.82	0.88	0.90	0.94	0.95		
45	113	0.71	0.82	0.85	0.90	0.92		
50	122	0.58	0.75	0.80	0.87	0.89		
55	131	0.41	0.67	0.74	0.83	0.86		
60	140	....	0.58	0.67	0.79	0.83	0.91	
70	158	....	0.35	0.52	0.71	0.76	0.87	
75	167	....	....	0.43	0.66	0.72	0.86	
80	176	....	....	0.30	0.61	0.69	0.84	
90	194	....	....	....	0.50	0.61	0.80	
100	212	....	....	....	....	0.51	0.77	
120	248	....	....	....	....	....	0.69	
140	284	....	....	....	....	....	0.59	

[a] **Aluminum Conductors.**—For aluminum conductors, the allowable current-carrying capacity shall be taken as 84 per cent of those given in the table for the respective sizes of copper conductor with the same kind of insulation.

18A. National Electrical Code Allowable Current-carrying Capacities Not More than Three Conductors in Raceway or Cable

(Based on Room Temperature of 30°C. (86°F.); All Current-carrying Capacities Given in Amperes; the neutral conductor in an approximately balanced three-phase four-wire system is not counted as a current-carrying wire)

Size A.w.g. or cir. mils	Rubber Type R, Type RW, Type RU Type RUW (14-2) / Thermoplastic, Type T Type TW	Rubber Type RH	Paper / Thermoplastic asbestos Type TA / Var-Cam Type V / Asbestos Var-Cam Type AVB	Asbestos Var-Cam Type AVA, Type AVL	Impregnated Asbestos Type AI (14–8), Type AIA	Asbestos Type A (14–8) Type AA
14	15	15	25	30	30	30
12	20	20	30	35	40	40
10	30	30	40	45	50	55
8	40	45	50	60	65	70
6	55	65	70	80	85	95
4	70	85	90	105	115	120
3	80	100	105	120	130	145
2	95	115	120	135	145	165
1	110	130	140	160	170	190
1/0	125	150	155	190	200	225
2/0	145	175	185	215	230	250
3/0	165	200	210	245	265	285
4/0	195	230	235	275	310	340
250,000	215	255	270	315	335	
300,000	240	285	300	345	380	
350,000	260	310	325	390	420	
400,000	280	335	360	420	450	
500,000	320	380	405	470	500	
600,000	355	420	455	525	545	
700,000	385	460	490	560	600	
750,000	400	475	500	580	620	
800,000	410	490	515	600	640	
900,000	435	520	555			
1,000,000	455	545	585	680	730	
1,250,000	495	590	645			
1,500,000	520	625	700	785		
1,750,000	545	650	735			
2,000,000	560	665	775	840		

Correction Factor for Room Temperatures over 30°C. (86°F.)

°C.	°F.						
40	104	0.82	0.88	0.90	0.94	0.95	
45	113	0.71	0.82	0.85	0.90	0.92	
50	122	0.58	0.75	0.80	0.87	0.89	
55	131	0.41	0.67	0.74	0.83	0.86	
60	140	....	0.58	0.67	0.79	0.83	0.91
70	158	....	0.35	0.52	0.71	0.76	0.87
75	167	....	....	0.43	0.66	0.72	0.86
80	176	....	....	0.30	0.61	0.69	0.84
90	194	....	....	....	0.50	0.61	0.80
100	212	....	....	....	....	0.51	0.77
120	248	....	....	....	....	....	0.69
140	284	....	....	....	....	....	0.59

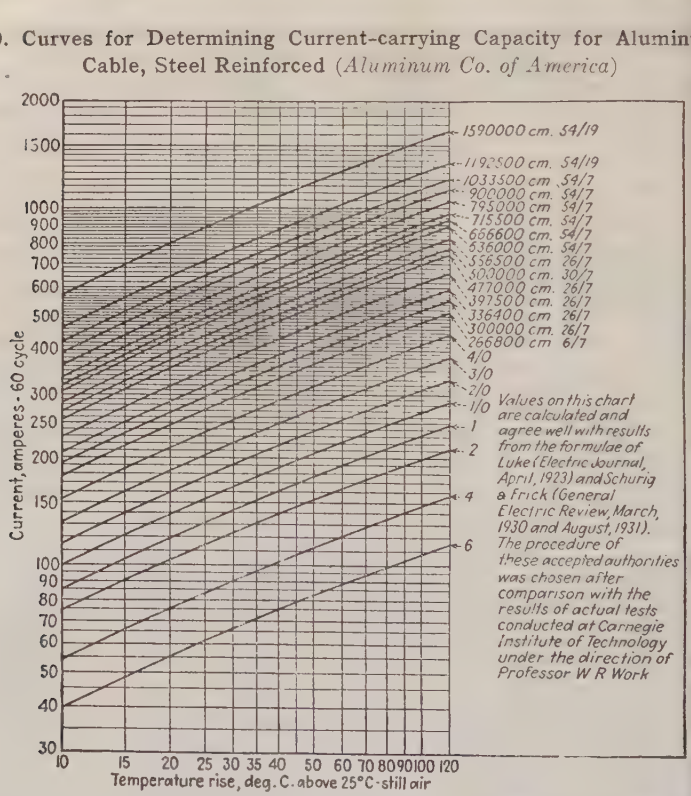
18B. National Electrical Code Allowable Current-carrying Capacity of Flexible Cord and Fixture Wire in Amperes
(Based on Room Temperature of 30°C. (86°F.))

Size, A.w.g.	Flexible cord						Fixture wire	
	Rubber and cotton Types CT, CTJ	Rubber Types PO, C, PD, P, PWP, K, E, EO	Rubber Types S, SO, SJ, SJO, SV, SU, SUO, POSJ	Types AFS, AFSJ, HC, HPD, HSJ	Types AVPO, AVPD	Cotton Types CFC,[a] CFPO,[a] CFPD[a]	Rubber	Thermoplastic Types TF, TFF
	Rubber and asbestos Types AT, ATJ	Armored Type CA	Thermoplastic Types ST, SJT, SVT, POT			Asbestos Types AFC,[a] AFPO,[a] AFPD[a]	Types RF-64, RF-32, FF-64, FF-32, RUF, RUFF	Cotton Type CF[a] / Asbestos Type AF[a]
27[b]	0.5							
18	...	5	7	10	17	6	5	6
17	...	..	..	12				
16	...	7	10	15	22	8	7	8
15	...	..	..	17				
14	...	15	15	20	28	17	..	17
12	...	20	20	..	36			
10	...	25	25	..	47			
8	...	35						
6	...	45						
4	...	60						
2	...	80						

[a] These types are used almost exclusively in fixtures where they are exposed to high mperatures, and ampere ratings are assigned accordingly.
[b] Tinsel cord.

More than Three Conductors in a Cord.—This table gives the allowa- e current-carrying capacities for not more than three current-carrying nductors in a cord. If the number of current-carrying conductors in cord is from four to six, the allowable current-carrying capacity of ch conductor shall be reduced to 80 per cent of the values in the table.

19. Curves for Determining Current-carrying Capacity for Aluminu Cable, Steel Reinforced (*Aluminum Co. of America*)



20. Current-carrying Capacity of Parkway Cables Buried Directly i Ground[a]

Conductor size, A.w.g. or cir. mils	Max. allowable current per conductor		Conductor size, A.w.g. or cir. mils	Max. allowable current per conductor	
	Single-conductor cable, amp.	Three-conductor cable, amp.		Single-conductor cable, amp.	Three-conductor cable, amp
8	85	60	3/0	335	225
6	115	80	4/0	385	255
4	150	100	250,000	445	285
2	195	130	300,000	470	315
1	220	150	350,000	515	345
1/0	255	170	400,000	555	375
2/0	295	195	500,000	635	425

[a] Table based on earth temperature of 20°C. (68°F.). Rubber-insulated conductors accordance with I.P.C.E.A. specification. Average soil condition, sandy loam, 10 p cent moisture. Average depth of burial 18 in. Other cables sufficiently far away prevent mutual heating. Rated voltages up to 5 kv., grounded neutral.

21. Number of Conductors in Conduit or Tubing; One to Nine Conductors, Rubber-covered, Types R, RW, RU, RUW, RH, RUF, and RF-32 Thermoplastic Types T, TF, and TW and Varnished Cambric Type V, 600 Volts

(National Electrical Code)

Size of conductor, A.w.g. or cir. mils	Number of conductors in one conduit or tubing								
	1	2	3	4	5	6	7	8	9
	Size of conduit or tubing, in.								
18	½	½	½	½	½	½	½	½	¾
16	½	½	½	½	½	½	¾	¾	¾
14	½	½	½	½	¾	¾	¾	1	1
12	½	½	½	¾	¾	1	1	1	1¼
10	½	¾	¾	¾	1	1	1¼	1¼	1¼
8	½	¾	1	1	1¼	1¼	1¼	1¼	1½
6	½	1	1¼	1¼	1½	1½	2	2	2
5	¾	1¼	1¼	1¼	1½	2	2	2	2
4	¾	1¼	1¼ [a]	1½	2	2	2	2	2½
3	¾	1¼	1¼	1½	2	2	2	2½	2½
2	¾	1¼	1½	1½	2	2	2½	2½	2½
1	¾	1½	1½	2	2	2½	2½	3	3
0	1	1½	2	2	2½	2½	3	3	3
2/0	1	2	2	2½	2½	3	3	3	3½
3/0	1	2	2	2½	3	3	3	3½	3½
4/0	1¼	2	2½	2½	3	3	3½	3½	4
250,000	1¼	2½	2½	3	3	3½	4	4	4½
300,000	1¼	2½	2½	3	3½	4	4	4½	4½
350,000	1¼	3	3	3½	3½	4	4½	4½	5
400,000	1½	3	3	3½	4	4	4½	5	5
500,000	1½	3	3	3½	4	4½	5	5	6
600,000	2	3½	3½	4	4½	5	6	6	6
700,000	2	3½	3½	4½	5	5	6	6	
750,000	2	3½	3½	4½	5	6	6	6	
800,000	2	3½	4	4½	5	6	6		
900,000	2	4	4	5	6	6	6		
1,000,000	2	4	4	5	6	6			
1,250,000	2½	4½	4½	6	6				
1,500,000	3	5	5	6					
1,750,000	3	5	6	6					
2,000,000	3	6	6						

[a] Where a service run of conduit or electrical metallic tubing does not exceed 50 ft. in ngth and does not contain more than the equivalent of two quarter bends from end to d, two No. 4 insulated and one No. 4 bare conductors may be installed in 1-in. conduit tubing.

22. Number of Conductors in Conduit or Tubing; Lead-covered Types RL, RHL, and VL, 600 Volts

(National Electrical Code)

Size of conductor, A.w.g. or cir. mils	Number of conductors in one conduit or tubing											
	Single-conductor cable				2-conductor cable				3-conductor cable			
	1	2	3	4	1	2	3	4	1	2	3	4
	Size of conduit or tubing, in.											
14	½	¾	¾	1	½	1	1	1¼	¾	1¼	1½	1½
12	½	¾	¾	1	¾	1	1¼	1¼	1	1¼	1½	2
10	½	¾	1	1	¾	1¼	1¼	1½	1	1½	2	2
8	½	1	1¼	1½	1	1¼	1½	2	1	2	2	2½
6	¾	1¼	1½	1½	1¼	1½	2	2½	1¼	2½	3	3
4	¾	1¼	1½	1½	1¼	2	2½	2½	1½	3	3	3½
3	¾	1¼	1½	2	1¼	2	2½	3	1½	3	3	3½
2	1	1¼	1½	2	1¼	2	2½	3	1½	3	3½	4
1	1	1½	2	2	1½	2½	3	3½	2	3½	4	4½
0	1	2	2	2½	2	2½	3	3½	2	4	4½	5
2/0	1	2	2	2½	2	3	3½	4	2½	4	4½	5
3/0	1¼	2	2½	2½	2	3	3½	4	2½	4½	4½	6
4/0	1¼	2½	2½	3	2½	3	3½	4½	3	5	6	6
250,000	1¼	2½	3	3	...	...	...	...	3	6	6	
300,000	1½	3	3	3½	...	...	...	...	3½	6	6	
350,000	1½	3	3	3½	...	...	...	...	3½	6	6	
400,000	1½	3	3	3½	...	...	...	...	3½	6	6	
500,000	1½	3	3½	4	...	...	...	...	4	6		
600,000	2	3½	4	4½								
700,000	2	4	4	5								
750,000	2	4	4	5								
800,000	2	4	4½	5								
900,000	2½	4	4½	5								
1,000,000	2½	4½	4½	6								
1,250,000	3	5	5	6								
1,500,000	3	5	6	6								
1,750,000	3	6	6									
2,000,000	3½	6	6									

The above sizes apply to straight runs or with nominal offsets equivalent to not mor than two quarter bends.

It is recommended that bends have a minimum radius of curvature at the inner edge o the bend of not less than ten times the internal diameter of the conduit or tubing.

23. Number of Conductors in Conduit or Tubing; (More than Nine Conductors, Rubber-covered, Types R, RW, RUW, RU, RUF, RF-32, and RH, 600 Volts, Thermoplastic Types TF, T, and TW, 600 Volts When Specifically Permitted by the Code)[a]

(National Electrical Code)

Size of conductor, A.w.g. or cir. mils	Size of conduit or tubing						
	¾ in.	1 in.	1¼ in.	1½ in.	2 in.	2½ in.	3 in.
	Max. number of conductors in conduit or tubing						
18	12	20	35	49	80	115	176
16	10	17	30	41	68	97	150
14	..	10	18	25	40	59	90
12	..	..	15	21	35	50	77
10	..	..	13	17	29	41	64
8	..	..	..	10	17	25	38
6	..	..	..	..	..	15	23

[a] More than nine conductors are permitted in a single conduit for conductors between a motor and its controller, stage pocket and border circuits, sign flashers, elevator control conductors, and signal and control circuits.

24. Combination of Conductors in Conduit or Tubing

(National Electrical Code)

For groups or combinations of conductors not included in Tables 21 to 23, it is recommended that the conduit or tubing be of such size that the sum of the cross-sectional areas of the individual conductors will not be more than the percentage of the interior cross-sectional area of the conduit or tubing as shown in the following table:

Percentages of Area of Conduit or Tubing to Be Occupied by Conductors

Type of conductors	Number of conductors				
	1	2	3	4	Over 4
	Per cent				
Conductors (not lead covered)	53	31	43	40	40
Lead-covered conductors	55	30	40	38	35
For rewiring of existing raceways for increased load where it is impracticable to increase the size of the raceway because of structural conditions	60	40	50	50	50

See Tables 25 to 27*A* for dimensions of conductors, conduit, and tubing.

25. Dimensions and Per Cent Area of Conduit and Tubing

(Areas of Conduit or Tubing for the Combinations of Wires Permitted by Table 24)

Trade size	Internal diameter, in.	Area, sq. in.									
			Not lead covered				Lead covered				
		Total 100%	1 conductor 53%	2 conductor 31%	3 conductor 43%	4 conductor and over 40%	1 conductor 55%	2 conductor 30%	3 conductor 40%	4 conductor 38%	Over 4 conductor 35%
½	0.622	0.30	0.16	0.09	0.13	0.12	0.17	0.09	0.12	0.11	0.11
¾	0.824	0.53	0.28	0.16	0.23	0.21	0.29	0.16	0.21	0.20	0.19
1	1.049	0.86	0.46	0.27	0.37	0.34	0.47	0.26	0.34	0.33	0.30
1¼	1.380	1.50	0.80	0.47	0.65	0.60	0.83	0.45	0.60	0.57	0.53
1½	1.610	2.04	1.08	0.63	0.88	0.82	1.12	0.61	0.82	0.78	0.71
2	2.067	3.36	1.78	1.04	1.44	1.34	1.85	1.01	1.34	1.28	1.18
2½	2.469	4.79	2.54	1.48	2.06	1.92	2.63	1.44	1.92	1.82	1.68
3	3.068	7.38	3.91	2.29	3.17	2.95	4.06	2.21	2.95	2.80	2.58
3½	3.548	9.90	5.25	3.07	4.26	3.96	5.44	2.97	3.96	3.76	3.47
4	4.026	12.72	6.74	3.94	5.47	5.09	7.00	3.82	5.09	4.83	4.45
4½	4.506	15.95	8.45	4.94	6.86	6.38	8.77	4.78	6.38	6.06	5.57
5	5.047	20.00	10.60	6.20	8.60	8.00	11.00	6.00	8.00	7.60	7.00
6	6.065	28.89	15.31	8.96	12.42	11.56	15.89	8.67	11.56	10.98	10.11

25A. Maximum Size of Conductor for Installation in Liquid-tight Flexible Metal Conduit

Trade Size of Conduit	Maximum Size of Conductor
⅜	16
½	12
¾	8
1	6
1¼	2

26. Dimensions of Rubber-, Varnished-cambric, and Thermoplastic-insulated Conductors, 600 Volts or Less

(Types R, RF-32, RH, RU, RUF, RW, RUW, V, T, TF, and TW)

Size, A.w.g. or cir. mils	Types RF-32, R, RH, RW, V		Types TF, T, TW, RU,[a] RUF, RUW	
	Approx. diam., in.	Approx. area, sq. in.	Approx. diam., in.	Approx. area, sq. in.
18	0.146	0.0167	0.106	0.0088
16	0.158	0.0196	0.118	0.0109
14	0.171[b]	0.0230[b]	0.131	0.0135
12	0.188[b]	0.0278[b]	0.148	0.0172
10	0.242	0.0460	0.169	0.0224
8	0.311	0.0760	0.228	0.0408
6	0.397	0.1238	0.323	0.0819
4	0.452	0.1605	0.372	0.1087
3	0.481	0.1817	0.401	0.1263
2	0.513	0.2067	0.433	0.1473
1	0.588	0.2715	0.508	0.2027
1/0	0.629	0.3107	0.549	0.2367
2/0	0.675	0.3578	0.595	0.2781
3/0	0.727	0.4151	0.647	0.3288
4/0	0.785	0.4840	0.705	0.3904
250,000	0.868	0.5917	0.788	0.4877
300,000	0.933	0.6837	0.843	0.5581
350,000	0.985	0.7620	0.895	0.6291
400,000	1.032	0.8365	0.942	0.6969
500,000	1.119	0.9834	1.029	0.8316
600,000	1.233	1.1940	1.143	1.0261
700,000	1.304	1.3355	1.214	1.1575
750,000	1.339	1.4082	1.249	1.2252
800,000	1.372	1.4784	1.282	1.2908
900,000	1.435	1.6173	1.345	1.4208
1,000,000	1.494	1.7531	1.404	1.5482
1,250,000	1.676	2.2062	1.577	1.9532
1,500,000	1.801	2.5475	1.702	2.2748
1,750,000	1.916	2.8895	1.817	2.5930
2,000,000	2.021	3.2079	1.922	2.9013

[a] No. 14 to No. 2.

[b] The diameters of Type RW in Nos. 14 and 12 are 0.204 and 0.221, respectively, and the areas are 0.0327 and 0.0384, respectively. The diameter of Type V in No. 14 is 0.0203 and of No. 12 is 0.22; the area of Type V in No. 14 is 0.033 and of No. 12 is 0.038.

Numbers 18 to 8, solid conductor; No. 6 and larger, stranded.

For all other types and insulation of wires, see Div. 2. For the dimensions of lead-covered wires, see Table 27.

27. Dimensions of Lead-covered Conductors, 600 Volts or Less (Type RL, RUL, and RHL)

Size of conductor, A.w.g. or cir. mils	Single conductor		2-conductor		3-conductor	
	Diam.	Area	Diam.	Area	Diam.	Area
14	0.28	0.062	0.28 × 0.47	0.115	0.59	0.273
12	0.29	0.066	0.31 × 0.54	0.146	0.62	0.301
10	0.35	0.096	0.35 × 0.59	0.180	0.68	0.363
8	0.41	0.132	0.41 × 0.71	0.255	0.82	0.528
6	0.49	0.188	0.49 × 0.86	0.369	0.97	0.738
4	0.55	0.237	0.54 × 0.96	0.457	1.08	0.916
2	0.60	0.283	0.61 × 1.08	0.578	1.21	1.146
1	0.67	0.352	0.70 × 1.23	0.756	1.38	1.49
0	0.71	0.396	0.74 × 1.32	0.859	1.47	1.70
1/0	0.76	0.454	0.79 × 1.41	0.980	1.57	1.94
3/0	0.81	0.515	0.84 × 1.52	1.123	1.69	2.24
4/0	0.87	0.593	0.90 × 1.64	1.302	1.85	2.68
250,000	0.98	0.754	.....	.....	2.02	3.20
300,000	1.04	0.85	.....	.....	2.15	3.62
350,000	1.10	0.95	.....	.....	2.26	4.02
400,000	1.14	1.02	.....	.....	2.40	4.52
500,000	1.23	1.18	.....	.....	2.59	5.28

NOTE.—Nos. 14 to 8, solid conductors; No. 6 and larger, stranded conductors.

27A. Dimensions of Asbestos-varnished-cambric-insulated Conductors
(Types AVA, AVB, and AVL)

Size, A.w.g. or cir. mils	Type AVA		Type AVB		Type AVL	
	Approx. diam., in.	Approx. area, sq. in.	Approx. diam., in.	Approx. area, sq. in.	Approx. diam., in.	Approx. area, sq. in.
14	0.245	0.047	0.205	0.033	0.320	0.080
12	0.265	0.055	0.225	0.040	0.340	0.091
10	0.285	0.064	0.245	0.047	0.360	0.102
8	0.310	0.075	0.270	0.057	0.390	0.119
6	0.395	0.122	0.345	0.094	0.430	0.145
4	0.445	0.155	0.395	0.123	0.480	0.181
2	0.505	0.200	0.460	0.166	0.570	0.255
1	0.585	0.268	0.540	0.229	0.620	0.300
1/0	0.625	0.307	0.580	0.264	0.660	0.341
2/0	0.670	0.353	0.625	0.307	0.705	0.390
3/0	0.720	0.406	0.675	0.358	0.755	0.447
4/0	0.780	0.478	0.735	0.425	0.815	0.521
250,000	0.885	0.616	0.855	0.572	0.955	0.715
300,000	0.940	0.692	0.910	0.649	1.010	0.800
350,000	0.995	0.778	0.965	0.731	1.060	0.885
400,000	1.040	0.850	1.010	0.800	1.105	0.960
500,000	1.125	0.995	1.095	0.945	1.190	1.118
550,000	1.165	1.065	1.135	1.01	1.265	1.26
600,000	1.205	1.140	1.175	1.09	1.305	1.34
650,000	1.240	1.21	1.210	1.15	1.340	1.41
700,000	1.275	1.28	1.245	1.22	1.375	1.49
750,000	1.310	1.35	1.280	1.29	1.410	1.57
800,000	1.345	1.42	1.315	1.36	1.440	1.63
850,000	1.375	1.49	1.345	1.43	1.470	1.70
900,000	1.405	1.55	1.375	1.49	1.505	1.78
950,000	1.435	1.62	1.405	1.55	1.535	1.85
1,000,000	1.465	1.69	1.435	1.62	1.565	1.93

NOTE.—Numbers 14 to 8, solid, No. 6 and larger, stranded; except AVL where all sizes are stranded.

28. Capacitor Ratings for Use with Open-type Three-phase 60-cycle Induction Motors

Motor rating, hp.	3,600 r.p.m.[a]		1,800 r.p.m.[a]		1,200 r.p.m.[a]		900 r.p.m.[a]		720 r.p.m.[a]		600 r.p.m.[a]	
	Max. capacitor rating, kva.	Reduction in line current, %	Max. capacitor rating, kva.	Reduction in line current, %	Max. capacitor rating, kva.	Reduction in line current, %	Max. capacitor rating, kva.	Reduction in line current, %	Max. capacitor rating, kva.	Reduction in line current, %	Max. capacitor rating, kva.	Reduction in line current, %
10	2.5	9	4.	11	4.	12	5.	17	5.	23	7.5	28
15	2.5	9	5.	11	5.	11	7.5	16	7.5	21	10.	26
20	5.	9	5.	10	5.	11	7.5	15	10.	20	12.5	24
25	5.	9	7.5	10	7.5	10	10.	14	10.	19	15.	22
30	7.5	9	10.	9	10.	10	10.	13	12.5	18	15.	21
40	10.	9	10.	9	10.	10	12.5	12	15.	16	17.5	19
50	12.5	9	12.5	9	12.5	9	15.	12	20.	15	22.5	17
60	15.	9	15.	8	15.	9	17.5	11	22.5	14	25.	16
75	17.5	9	17.5	8	17.5	8	20.	11	27.5	13	30.	15
100	22.5	9	22.5	8	22.5	8	25.	10	35.	12	37.5	14
125	25.	9	27.5	8	27.5	8	30.	9	40.	11	47.5	13
150	32.5	9	35.	8	35.	8	37.5	9	47.5	11	55.	13
200	42.5	9	42.5	8	42.5	8	45.	9	60.	10	67.5	12

[a] Synchronous speed.

If capacitors of a lower rating than the values given in the table are used, the percentage reduction in line current given in the table shall be reduced a corresponding amount.

29. Standard General-purpose-switch Sizes
(All Sizes in Amperes)

Regular open knife blade	Open Klamp-tite	Open toggle	Enclosed safety	Regular open knife blade	Open Klamp-tite	Open toggle	Enclosed safety
30	400	300	30	1,200	4,000	2,500	1,000
60	600	500	60	.....	5,000	3,000	1,200
100	800	600	100	.....	.....	4,000	2,400
200	1,000	800	200	.....	.....	5,000	
400	1,200	1,000	400	.....	.....	6,000	
600	1,600	1,200	600	.....	.....	8,000	
800	2,000	1,600	800	.....	.....	10,000	
	3,000	2,000					

30. Electrical Symbols for Architectural Plans.[a]

General Outlets

Ceiling	Wall	
○	—○	Outlet.
ⓒ	—ⓒ	Capped outlet.
ⓓ		Drop cord.
ⓔ	—ⓔ	Electrical outlet—for use only when circle used alone might be confused with columns, plumbing symbols, etc.
○	—ⓕ	Fan outlet.
ⓙ	—ⓙ	Junction box.
ⓛ	—ⓛ	Lamp holder.
ⓛ_{PS}	—ⓛ_{PS}	Lamp holder with pull switch.
ⓢ	—ⓢ	Pull switch.
ⓥ	—ⓥ	Outlet for vapor-discharge lamp.
ⓧ	—ⓧ	Exit-light outlet.
ⓒ	—ⓒ	Clock outlet (lighting voltage).

Convenience Outlets

=⊖	Duplex convenience outlet.
$=\ominus_{1,3}$	Convenience outlet other than duplex. 1-single, 3-triplex, etc.
$=\ominus_{WP}$	Weatherproof convenience outlet.
$=\ominus_{R}$	Range outlet.
=⊖$	Switch and convenience outlet.
=⊖R	Radio and convenience outlet.
◭	Special-purpose outlet (description in specifications).
⊙	Floor outlet.

Switch Outlets

$	Single-pole switch.
$\$_2$	Double-pole switch.
$\$_3$	Three-way switch.
$\$_4$	Four-way switch.
$\$_D$	Automatic door switch.
$\$_E$	Electrolier switch.
$\$_K$	Key-operated switch.
$\$_P$	Switch and pilot lamp.
$\$_{CB}$	Circuit breaker.
$\$_{WCB}$	Weatherproof circuit breaker.
$\$_{MC}$	Momentary-contact switch.

[a] These symbols have been prepared by a technical subcommittee of the A.S.A., Committee Z32, Standardization of Graphical Symbols and Abbreviations for Use on Drawings, and have been submitted for approval as an American Standard to replace the symbols shown in A.S.A. C10—1924.

The electrical symbols for architectural plans as finally approved by the A.S.A. as an American Standard will be announced by that body in due course of time.

$_{RC} Remote-control switch.

$_{WP} Weatherproof switch.

Special Outlets

Any standard symbol as given above with the addition of a lower-case subscript letter may be used to designate some special variation of standard equipment of particular interest in a specific set of architectural plans.

a,b,c-etc.

a,b,c-etc.

$ a,b,c-etc.

When used they must be listed in the Key of Symbols on each drawing and, if necessary, further described in the specifications.

Panels, Circuits, and Miscellaneous

Lighting panel.

Power panel.

Branch circuit—ceiling or wall.

Branch circuit—floor.

Note: Any circuit without further designation indicates a two-wire circuit. For a greater number of wires indicate as follows: —///— (3 wires), —//—//— (4 wires), etc.

Feeders.

Note: Use heavy lines and designate by number corresponding to listing in Feeder Schedule.

Underfloor duct and junction box—triple system.

Note: For double or single systems eliminate one or two lines. This symbol is equally adaptable to auxiliary system layouts.

G Generator.

M Motor.

I Instrument.

T Transformer.

Controller.

S Isolating Switch.

Auxiliary Systems

Push button.

Buzzer.

Bell.

Annunciator.

Telephone.

Telephone switchboard.

Clock (low voltage).

D Electric door opener.

F Fire-alarm bell.

F Fire-alarm station.

- City fire-alarm station.
- FA Fire-alarm central station.
- FS Automatic fire-alarm device.
- W Watchman's station.
- W Watchman's central station.
- H Horn.
- N Nurse's signal plug.
- M Maid's signal plug.
- R Radio outlet.
- SC Signal central station.
- Interconnection box.
- Battery.
- ——— Auxiliary system circuits.

NOTE: Any line without further designation indicates a two-wire circuit. For a greater number of wires designate with numerals in manner similar to ———— 12-#18W-¾"C., or designated by number corresponding to listing in schedule.

- $\square_{a,b,c}$ Special auxiliary outlets.

Subscript letters refer to notes on plans or detailed description in specifications.

31. Isolation by Elevation and Clear Working Space

Voltage between phases	Minimum vertical clearance of unguarded live parts above the floor or other working surface		Minimum horizontal clearance of unguarded live parts	
	Ft.	In.	Ft.	In.
600	8	0	3	2
2,300	8	0	3	3
6,600	8	0	3	4
11,000	9	0	3	6
22,000	9	3	3	9
33,000	9	6	4	0
44,000	9	10	4	4
66,000	10	5	4	11
88,000	11	0	5	6
110,000	11	7	6	1
132,000	12	2	6	8

32. Maximum Diameter of Cable to Be Installed in Various Sizes and Types of Ducts for Underground Duct Installation

(All Dimensions Are in Inches)

Nominal diam. of duct	Condition (see notes below)	Monolithic concrete		Single-camp. tile		Multiple tile		Fiber duct		Iron pipe		"Stone" duct	
		Actual diam. of duct	Diam. of cable	Actual diam. of duct	Diam. of cable	Actual size of duct	Diam. of cable	Actual diam. of duct	Diam. of cable	Actual diam. of duct	Diam. of cable	Actual diam. of duct	Diam. of cable
3	(1) a	3 3/8	2 3/4	3 3/8	2 7/8	3 3/8	2 7/8	3	2 1/2	3	2 3/8		
	(1) b	3 3/8	2 5/8	3 3/8	2 3/4	3 3/8	2 3/4	3	2 3/8	3	2 1/4		
	(1) c	3 3/8	2 1/2	3 3/8	2 5/8	3 3/8	2 5/8	3	2 1/4	3	2 1/8		
	(2) a	3 3/8	3	3 3/8	3 1/8	3 3/8	3 1/8	3	2 3/4	3	2 5/8		
	(2) b	3 3/8	2 7/8	3 3/8	3	3 3/8	3	3	2 5/8	3	2 1/2		
	(2) c	3 3/8	2 3/4	3 3/8	2 7/8	3 3/8	2 7/8	3	2 1/2	3	2 3/8		
3 1/2	(1) a	3 7/8	3 1/4	3 5/8	3 1/8	3 5/8	3 1/8	3 1/2	3	3 1/2	2 7/8	3 1/2	3
	(1) b	3 7/8	3 1/8	3 5/8	3	3 5/8	3	3 1/2	2 7/8	3 1/2	2 3/4	3 1/2	2 7/8
	(1) c	3 7/8	3	3 5/8	2 7/8	3 5/8	2 7/8	3 1/2	2 3/4	3 1/2	2 5/8	3 1/2	2 3/4
	(2) a	3 7/8	3 1/2	3 5/8	3 3/8	3 5/8	3 3/8	3 1/2	3 1/4	3 1/2	3 1/8	3 1/2	3 1/8
	(2) b	3 7/8	3 3/8	3 5/8	3 1/4	3 5/8	3 1/4	3 1/2	3 1/8	3 1/2	3	3 1/2	3
	(2) c	3 7/8	3 1/4	3 5/8	3 1/8	3 5/8	3 1/8	3 1/2	3	3 1/2	2 7/8	3 1/2	2 7/8
4	(1) a	4 1/8	3 3/8	4 3/8	3 3/4	...	...	4	3 3/8	4	3 1/4	4	3 3/8
	(1) b	4 1/8	3 1/4	4 3/8	3 5/8	...	...	4	3 1/4	4	3 1/8	4	3 1/4
	(1) c	4 1/8	3 1/8	4 3/8	3 1/2	...	...	4	3 1/8	4	3	4	3 1/8
	(2) a	4 1/8	3 5/8	4 3/8	4	...	...	4	3 5/8	4	3 1/2	4	3 1/2
	(2) b	4 1/8	3 1/2	4 3/8	3 7/8	...	...	4	3 1/2	4	3 3/8	4	3 3/8
	(2) c	4 1/8	3 3/8	4 3/8	3 3/4	...	...	4	3 3/8	4	3 1/4	4	3 1/4
5	(1) a	4 7/8	4 1/8	...	...	...	...	5	4 1/4	5	4 1/8		
	(1) b	4 7/8	4	...	...	...	...	5	4 1/8	5	4		
	(1) c	4 7/8	3 7/8	...	...	...	...	5	4	5	3 7/8		
	(2) a	4 7/8	4 3/8	...	...	...	...	5	4 1/2	5	4 3/8		
	(2) b	4 7/8	4 1/4	...	...	...	...	5	4 3/8	5	4 1/4		
	(2) c	4 7/8	4 1/8	...	...	...	...	5	4 1/4	5	4 1/8		

For more than one cable, the diameter is that of the circumscribing circle.

NOTE.—For dimensions of cable refer to Div. 2.

(1) Conservative maximum size.

(2) Exceptional maximum size.

[a] Straight section less than 300 ft. long.

[b] Straight section from 300 to 600 ft. long.

[c] Curved section less than 300 ft. long, one or two bends of 50- to 250-ft. radius.

33. Ordinary Ratings of Overload Protective Devices in Amperes

Plug fuses	Cartridge fuses	Large-sized magnetic breakers		Small magnetic breakers made by Heinemann Elec. Co.	Thermal breakers	Time-lag fuses		Overload relays and releases for use with manual or magnetic switches
		Rating	Range of setting			Screw-base type	Cartridge type	
	1	3	3–6	Any ampere or fractional-ampere rating from 50 ma. to 35 amp.				
3	3	6	6– 12		10	1.0	1.	½
6	6	10	10– 20		15	1.25	1.25	¾
10	10	15	15– 30		20	1.6	1.6	1
15	15	20	20– 40		25	2.0	2.0	1½
20	20	25	25– 50		35	2.5	2.5	2
25	25	35	35– 70		50	3.2	3.2	2½
30	30	50	50– 100		70	4.0	4.0	3
.	35	70	70– 140		90	5.0	5.0	3½
.	40	90	90– 180		100	6.25	6.25	4
..	45	100	100– 200		125	8.0	8	4½
	50	125	125– 250		150	10.0	10	5
.	60	150	150– 300		175	12.0	12	6
..	70	175	175– 350		200	14.0	15	7
..	80	200	200– 400		225	15.0	20	8
..	90	225	225– 450		250	20.0	25	9
..	100	250	250– 500		275	25.0	30	10
..	110	275	275– 550		300	30.0	35	12
..	125	300	300– 600		325	.....	40	14
..	150	325	325– 650		350	.....	45	16
..	175	350	350– 700		400	.....	50	18
..	200	400	400– 800		450	.....	60	20
..	225	500	500– 1,000		500	.....	70	22
..	250	600	600– 1,200		550	.....	80	24
..	300	800	800– 1,600		600	.....	90	28
..	350	1,000	1,000– 2,000		...	.....	100	32
..	400	1,200	1,200– 2,400		...	.....	110	36
..	450	1,600	1,600– 3,200		...	.....	125	40
..	500	2,000	2,000– 4,000		...	.....	150	45
..	600	2,500	2,500– 5,000		...	.....	175	50
..	...	3,000	3,000– 6,000		...	.....	200	55
..	...	4,000	4,000– 8,000		...	.....	225	60
..	...	5,000	5,000–10,000		...	.....	250	65
.	...	6,000	6,000–12,000		...	.....	300	70
..	...	8,000	8,000–16,000		...	.....	350	75
..	...	10,000	10,000–20,000		...	.....	400	80
..	...	.....	.....		...	.....	450	
..	...	.....	.....		...	.....	500	
..	...	.....	.....		...	.....	600	

34. Motor-wiring Table—Sizes of Conductors, Conduits, Motor Overcurrent Protective Devices, Motor-circuit Switches, and Unfused Disconnecting Switches

Full-load current rating of motor, amp.	Min. size of conductor and conduit when using: Type R, RW, T, TW wire — Conductor size, A.w.g. or cir. mils	Conduit size, in. — 2 wires	Conduit size, in. — 3 wires	Type RH wire — Conductor size, A.w.g. or cir. mils	Conduit size, in. — 2 wires	Conduit size, in. — 3 wires	Type V wire — Conductor size, A.w.g. or cir. mils	Conduit size, in. — 2 wires	Conduit size, in. — 3 wires	Motor overcurrent protective device for running protection of motors — Max. rating of N.E.C. fuses, amp.	Max. setting of time-limit protective device, amp.	Motor-circuit switch	Min. size of unfused disconnecting switch, amp. Switch S_B in Fig. 161 of Div. 7 If fused, switch may be of this size but must have fuse clips of size in accordance with Sec. **36**, amp.
1[a]	14	½	½	14	½	½	.....	.....	.....	2[b]	1.25[b]	All motor-circuit switches (switch S_M in Figs. 161 and 162 of Div. 7) must be rated in horsepower and have a rating at least as great as the full-load horsepower rating of the motor. If they are fused, they must have fuse clips of a size in accordance with Sec. **36**.	30
2[a]	14	½	½	14	½	½	.....	.....	.....	3[b]	2.50[b]		30
3[a]	14	½	½	14	½	½	.....	.....	.....	4[b]	3.75[b]		30
4[a]	14	½	½	14	½	½	.....	.....	.....	6[b]	5.0[b]		30
5[a]	14	½	½	14	½	½	.....	.....	.....	8[b]	6.25[b]		30
6[a]	14	½	½	14	½	½	.....	.....	.....	8[b]	7.50[b]		30
7	14	½	½	14	½	½	.....	.....	.....	10[b]	8.75[b]		30
8	14	½	½	14	½	½	.....	.....	.....	10[b]	10.0[b]		30
9	14	½	½	14	½	½	.....	.....	.....	12[b]	11.25[b]		30
10	14	½	½	14	½	½	.....	.....	.....	15[b]	12.50[b]		30
11	14	½	½	14	½	½	.....	.....	.....	15[b]	13.75[b]		30
12	14	½	½	14	½	½	.....	.....	.....	15	15.00		30
13	12	½	½	12	½	½	.....	.....	.....	20	16.25		30
14	12	½	½	12	½	½	.....	.....	.....	20	17.50		30
15	12	½	½	12	½	½	.....	.....	.....	20	18.75	.....	30
16	12	½	½	12	½	½	.....	.....	.....	20	20.00	.....	30
17	10	¾	¾	10	¾	¾	.....	.....	.....	25	21.25	.....	30
18	10	¾	¾	10	¾	¾	.....	.....	.....	25	22.50	.....	30
19	10	¾	¾	10	¾	¾	.....	.....	.....	25	23.75	.....	30
20	10	¾	¾	10	¾	¾	.....	.....	.....	25	25.0	.....	30

22	10	3/4	3/4	10	3/4	3/4	.....	...	...	30	27.50	.....		
24	10	3/4	3/4	10	3/4	1	.....	...	...	30	30.00	.....	30	
26	8	3/4	1	8	3/4	1	.....	...	...	35	32.50	.....	30	
28	8	3/4	1	8	3/4	1	.....	...	...	35	35.00	.....	30	
30	8	3/4	1	8	3/4	1	.....	...	...	40	37.50	.....	60	
													60	
32	8	3/4	1	8	3/4	1	.....	...	...	40	40.00	.....		
34	6	1	1 1/4	8	3/4	1	.....	...	...	45	42.50	.....	60	
36	6	1	1 1/4	8	3/4	1	.....	...	...	45	45.00	.....	60	
38	6	1	1 1/4	6	1	1 1/4	.....	...	...	50	47.50	.....	60	
40	6	1	1 1/4	6	1	1 1/4	.....	...	...	50	50.00	.....	60	
													60	
42	6	1	1 1/4	6	1	1 1/4	.....	...	...	50	52.50	.....		
44	6	1	1 1/4	6	1	1 1/4	.....	...	...	60	55.0	.....	60	
46	4	1 1/4	1 1/4	6	1	1 1/4	.....	...	...	60	57.50	.....	60	
48	4	1 1/4	1 1/4	6	1	1 1/4	.....	...	...	60	60.0	.....	60	
50	4	1 1/4	1 1/4	6	1	1 1/4	.....	...	...	60	62.50	.....	60	
													60	
52	4	1 1/4	1 1/4	6	1	1 1/4	.....	...	...	70	65.0	.....		
54	4	1 1/4	1 1/4	4	1 1/4	1 1/4	6	1	1 1/4	70	67.50	.....	60	
56	4	1 1/4	1 1/4	4	1 1/4	1 1/4	5	1 1/4	1 1/4	70	70.00	.....	100	
58	3	1 1/4	1 1/4	4	1 1/4	1 1/4	5	1 1/4	1 1/4	70	72.50	.....	100	
60	3	1 1/4	1 1/4	4	1 1/4	1 1/4	5	1 1/4	1 1/4	80	75.00	.....	100	
													100	
62	3	1 1/4	1 1/4	4	1 1/4	1 1/4	5	1 1/4	1 1/4	80	77.50	.....		
64	3	1 1/4	1 1/4	4	1 1/4	1 1/4	4	1 1/4	1 1/4	80	80.00	.....	100	
66	2	1 1/4	1 1/2	4	1 1/4	1 1/4	4	1 1/4	1 1/4	80	82.50	.....	100	
68	2	1 1/4	1 1/2	4	1 1/4	1 1/4	4	1 1/4	1 1/4	90	85.00	.....	100	
70	2	1 1/4	1 1/2	3	1 1/4	1 1/4	4	1 1/4	1 1/4	90	87.50	.....	100	
													100	
72	2	1 1/4	1 1/2	3	1 1/4	1 1/4	3	1 1/4	1 1/4	90	90.00	.....		
74	2	1 1/4	1 1/2	3	1 1/4	1 1/4	3	1 1/4	1 1/4	90	92.50	.....	100	
76	2	1 1/4	1 1/2	3	1 1/4	1 1/4	3	1 1/4	1 1/4	100	95.00	.....	100	
78	1	1 1/2	1 1/2	3	1 1/4	1 1/4	3	1 1/4	1 1/2	100	97.50	.....	100	
80	1	1 1/2	1 1/2	3	1 1/4	1 1/4	3	1 1/4	1 1/4	100	100.00	.....	100	

[a] For the grouping of small motors under the protection of a single set of fuses, see Sec. **436**, Div. 7.
[b] For running protection of motors of 1 hp. or less, see Sec. **436**, Div. 7.

Motor-wiring Table—Sizes of Conductors, Conduits, Motor Overcurrent Protective Devices, Motor-circuit Switches, and Unfused Disconnecting Switches *(Continued)*

Full-load current rating of motor, amp.	Min. size of conductor and conduit when using								Motor overcurrent protective device for running protection of motors		Motor-circuit switch	Min. size of unfused disconnecting switch, amp. Switch *Ss* in Fig. 161 of Div. 7 If fused, switch may be of this size but must have fuse clips of size in accordance with Sec. **36**, amp.
	Type R, RW, T, TW wire			Type RH wire			Type V wire					
	Conductor size, A.w.g. or cir. mils	Conduit size, in.		Conductor size, A.w.g. or cir. mils	Conduit size, in.		Conductor size, A.w.g. or cir. mils	Conduit size, in.		Max. rating of N.E.C. fuses, amp.	Max. setting of time-limit protective device, amp.		
		2 wires	3 wires		2 wires	3 wires		2 wires	3 wires				
82	1	1½	1½	2	1¼	1½	3	1¼	1¼	110	102.50	.....	100
84	1	1½	1½	2	1¼	1½	2	1¼	1½	110	105.00	.....	100
86	1	1½	1½	2	1¼	1½	2	1¼	1½	110	107.50	.....	100
88	1/0	1½	2	2	1¼	1½	2	1¼	1½	110	110.00	.....	200
90	1/0	1½	2	2	1¼	1½	2	1¼	1½	110	112.50	.....	200
92	1/0	1½	2	2	1¼	1½	2	1¼	1½	125	115.00	.....	200
94	1/0	1½	2	1	1½	1½	2	1¼	1½	125	117.50	.....	200
96	1/0	1½	2	1	1½	1½	1	1½	1½	125	120.00	.....	200
98	1/0	1½	2	1	1½	1½	1	1½	1½	125	122.50	.....	200
100	1/0	1½	2	1	1½	1½	1	1½	1½	125	125.00	.....	200
105	2/0	2	2	1	1½	1½	1	1½	1½	150	131.5	.....	200
110	2/0	2	2	1/0	1½	2	1	1½	1½	150	137.5	.....	200
115	2/0	2	2	1/0	1½	2	1/0	1½	2	150	144.0	.....	200
120	3/0	2	2	1/0	1½	2	1/0	1½	2	150	150.0	.....	200
125	3/0	2	2	2/0	2	2	1/0	1½	2	175	156.5	.....	200
130	3/0	2	2	2/0	2	2	2/0	2	2	175	162.5	.....	200
135	3/0	2	2	2/0	2	2	2/0	2	2	175	169.0	.....	200
140	4/0	2½	2½	3/0	2	2	2/0	2	2	175	175.0	.....	200
145	4/0	2½	2½	3/0	2	2	2/0	2	2	200	181.5	.....	200
150	4/0	2½	2½	3/0	2	2	3/0	2	2	200	187.5	.....	200

| | | |

35. Motor-wiring Table—Size of Branch-circuit Protective Devices and Size of Fuse Clips for Fused Motor Circuit or Disconnecting Switches

INSTRUCTIONS FOR USE OF TABLE 36

1. For motors marked with code letters (see Sec. **12**) use columns as follows:
   - *a.* All a-c, single-phase and polyphase, squirrel-cage or synchronous motors when started with full voltage or when started by resistor or reactor starting:
     Code letter *A*—use columns 14, 15, and 16.
     Code letters *B* to *E*—use columns 8, 9, and 10.
     Code letters *F* to *V*—use columns 2, 3, and 4.
   - *b.* All a-c, squirrel-cage or synchronous motors when started with autotransformer starting:
     Code letter *A*—use columns, 14, 15, and 16.
     Code letters *B* to *E*—use columns 11, 12, and 13.
     Code letters *F* to *V*—use columns 8, 9, and 10.
2. For motors not marked with code letters use columns as follows:
   - *a.* Single-phase motors of all types—use columns 2, 3, and 4.
   - *b.* Polyphase, squirrel-cage, normal-starting-current type when started with full voltage or when started by resistor or reactor starting—use columns 2, 3, and 4.
   - *c.* Polyphase, squirrel-cage, normal-starting-current type when started with autotransformer starting:
     When full-load current is not more than 30 amp.—use columns 8, 9, and 10.
     When full-load current is more than 30 amp.—use columns 11, 12, and 13.
   - *d.* Polyphase, squirrel-cage, low-starting-current type:
     When full-load current is not more than 30 amp.—use columns 5, 6, and 7.
     When full-load current is more than 30 amp.—use columns 11, 12, and 13.
   - *e.* Polyphase, squirrel-cage, high-resistance type:
     When full-load current is not more than 30 amp.—use columns 5, 6, and 7.
     When full-load current is more than 30 amp.—use columns 11, 12, and 13.
   - *f.* Automatic start, polyphase, squirrel-cage type—use columns 14, 15, and 16.
     If trouble is encountered with fuses or circuit breakers blowing on starting follow instructions under *e*.
   - *g.* Polyphase, commutator-type, brush-shifting type of motor:
     When full-load current is not more than 30 amp.—use columns 5, 6, and 7.

When full-load current is more than 30 amp.—use columns 11, 12, and 13.

h. Polyphase, polyspeed type of motor:

For heavy-starting duty—follow instructions under *e*.

For moderate-starting duty—follow instructions under *d*.

For light-starting duty—use columns 14, 15, and 16.

i. Fynn-Weichsel motors—use columns 14, 15, and 16.

j. Supersynchronous motors:

When started with full voltage or when started by resistor or reactor starting—use columns 2, 3, and 4.

When started with autotransformers—use columns 11, 12, and 13.

3. For general-purpose synchronous motors not marked with code letters, use columns as follows:

a. High-speed type and low-speed high-torque type, when started with full voltage or when started by resistor or reactor starting —use columns 2, 3, and 4.

b. High-speed type and low-speed, high-torque type when started with autotransformer starting:

When full-load current is not more than 30 amp.—use columns 8, 9, and 10.

When full-load current is more than 30 amp.—use columns 11, 12, and 13.

c. Low-speed, low-torque type:

When full-load current is not more than 30 amp.—use columns 5, 6, and 7.

When full-load current is more than 30 amp.—use columns 11, 12, and 13.

4. For polyphase, wound-rotor motors —use columns 14, 15, and 16.

5. For d-c motors—use columns 14, 15, and 16.

36. Maximum Allowable Ratings of Fuses, Setting of Time-limit-type Circuit Breakers, and Size of Fuse Clips for Fused Motor Circuit or Disconnecting Switches, for Given Percentages of Full-load Current Rating of Motor in Accordance with Secs. 12, 13, and 14

(All Values in Amperes)

Full-load current rating of motor, amp.	300 per cent fuses	250 per cent circuit-breaker setting	300 per cent fuse clips	250 per cent			250 per cent fuses	200 per cent circuit-breaker setting	250 per cent fuse clips	200 per cent			150 per cent		
				Fuses	Circuit-breaker setting	Fuse clips				Fuses	Circuit-breaker setting	Fuse clips	Fuses	Circuit-breaker setting	Fuse clips
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)
1–5	15	15	30	15	15		15	15		15	15		15	15	
6	20	15		15	15	30	15	15	30	15	15		15	15	
7	25	20		20	20		20	15		15	15		15	15	
8	25	20		20	20		20	20		20	20	30	15	15	
9–10	30	25		25	25		25	20		20	20		15	15	
11	35	30	60	30	30		30	25		25	25		20	20	30
12	40	30		30	30		30	25		25	25		20	20	
13	40	35		35	35		35	30		30	30		20	20	
14	45	35		35	35		35	30		30	30		25	25	
15	45	40		40	40		40	30		30	30		25	25	
16	50	40		40	40		40	35		35	35		25	25	
17	60	45		45	45		45	35		35	35		30	30	
18	60	45		45	45	60	45	40	60	40	40		30	30	
19–20	60	50		50	50		50	40		40	40	60	30	30	
22	70	60	100	60	55		60	45		45	45		35	35	60
24	80	60		60	60		60	50		50	50		40	40	
26	80	70		70	65		70	55		60	55		40	40	
28	90	70		70	70		70	60		60	60		45	45	
30	90	80		80	75		80	60		60	60		45	45	
32	100	80		80	80	100	80	65	100	70	65		50	50	
34	110	90		90	85		90	70		70	70	100	60	55	
36	110	90		90	90		90	75		80	75		60	55	
38	125	100		100	95		100	80		80	80		60	60	
40	125	100		100	100		100	80		80	80		60	60	

42	150	110			110	105			110	85		90		100		70		65	
44	150	110			110	110			110	90		90				70		70	
46	150	115			125	115			125	95		95				70		70	
48	150	120			125	120			125	100		100				80		75	
50	150	125			125	125			125	100		100				80		75	
			200																100
52	175	130			150	130			150	105		110				80		80	
54	175	135			150	135			150	110		110				90		85	
56	175	140			150	140			150	115		125				90		85	
58	175	145			150	145			150	120		125				90		90	
60	200	150			150	150		200	150	120	200	125				90		90	
62	200	155			175	155			175	125		125				100		95	
64	200	160			175	160			175	130		125				100		100	
66	200	165			175	165			175	135		150				100		100	
68	225	170			175	170			175	140		150				110		105	
70	225	175			175	175			175	140		150				110		105	
72	225	180			200	180			200	145		150		200		110		110	
74	225	185			200	185			200	150		150				125		115	
76	250	190			200	190			200	155		175				125		115	
78	250	195			200	195			200	160		175				125		120	
80	250	200			200	200			200	160		175				125		120	
82	250	205			225	205			225	165		175				125		125	
84	300	210		400	225	210			225	170		175				150		130	
86	300	215			225	215			225	175		175				150		130	
88	300	220			225	220			225	180		200				150		135	
90	300	225			225	225		400	225	180	400	200				150		135	
92	300	230			250	230			250	185		200				150		140	
94	300	235			250	235			250	190		200				150		145	
96	300	240			250	240			250	200		200				150		145	
98	300	245			250	245			250	200		200				150		150	
100	300	250			250	250			250	200		200				150		150	
105	350	265			300	265			300	210		225				175		160	
110	350	275			300	275			300	220		225				175		165	
115	350	290			300	290			300	230		250				175		175	
120	400	300			300	300			300	240		250		400		200		180	
125	400	315			350	315			350	250		250				200		190	

Maximum Allowable Ratings of Fuses, Setting of Time-limit-type Circuit Breakers, and Size of Fuse Clips for Fused Motor Circuit or Disconnecting Switches, for Given Percentages of Full-load Current Rating of Motor in Accordance with Secs. 12, 13, and 14 *(Continued)*

Full-load current rating of motor, amp.	300 per cent fuses	250 per cent circuit-breaker setting	300 per cent fuse clips	250 per cent			250 per cent fuses	200 per cent circuit-breaker setting	250 per cent fuse clips	200 per cent			150 per cent		
				Fuses	Circuit-breaker setting	Fuse clips				Fuses	Circuit-breaker setting	Fuse clips	Fuses	Circuit-breaker setting	Fuse clips
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)
130	400	325		350	325		350	260	400	300	260		200	195	
135	450	340		350	340	400	350	270		300	270		225	205	
140	450	350		350	350		350	280		300	280		225	210	
145	450	365		400	365		400	290		300	290		225	220	
150	450	375		400	375		400	300		300	300		225	225	
155	500	390		400	390		400	310		350	310	400	250	235	
160	500	400		400	400		400	320		350	320		250	240	
165	500	415	600	450	415		450	330		350	330		250	250	
170	500	425		450	425		450	340		350	340		300	255	
175	600	440		450	440		450	350		350	350		300	265	
180	600	450		450	450		450	360		400	360		300	270	400
185	600	465		500	465		500	370		400	370		300	280	
190	600	475		500	475		500	380		400	380		300	285	
195	600	490		500	490		500	390	600	400	390		300	295	
200	600	500		500	500	600	500	400		400	400		300	300	
210	...	525	...	600	525		600	420		450	420		350	315	
220	...	550	...	600	550		600	440		450	440		350	330	
230	...	575	...	600	575		600	460		500	460		350	345	
240	...	600	...	600	600		600	480		500	480		400	360	
250	...	625	...	...	625		...	500		500	500	600	400	375	
260	...	650	...	...	650	...	...	520	...	600	520		400	390	
270	...	675	...	...	675	...	...	540	...	600	540		450	405	
280	...	700	...	...	700	...	...	560	...	600	560		450	420	
290	...	725	...	...	725	...	...	580	...	600	580		450	435	600
300	...	750	...	...	750	...	...	600	...	600	600		450	450	

37. Maximum Allowable Voltage Drop

(In accordance with good practice; refer to Sec. 41 of Div. 3)

Circuits	Voltage drop, per cent	System voltages — Voltage drop						Remarks
		110	115	220	230	440	550	
For Total Drop of 3 Per Cent[a]								
Lighting:								
Branches	2	2.2	2.3	4.4	4.6			In accordance with recommendations of the National Electrical Code
Mains and feeders combined	1	1.1	1.2	2.2	2.3			
Total	3	3.3	3.5	6.6	6.9			
For Total Drop of 4 Per Cent								
Lighting:								
Branches	2	2.2	2.3	4.4	4.6			In accordance with recommendations prepared by Industry Committee on Interior Wiring Design
Mains and feeders combined	2	2.2	2.3	4.4	4.6			
Total	4	4.4	4.6	8.8	9.2			
For Total Drop of 5 Per Cent								
Power:								
Branches	2	2.2	2.3					In accordance with recommendations prepared by Industry Committee on Interior Wiring Design
Mains and feeders combined	3	3.3	3.5					
Total	5	5.5	5.8					
For Total Drop of 5 Per Cent								
Power:								
Branches	1	...	...	2.2	2.3	4.4	5.5	In accordance with recommendations prepared by Industry Committee an Interior Wiring Design
Mains and feeders combined	4	...	...	8.8	9.2	17.6	22.0	
Total	5	...	...	11.0	11.5	22.0	27.5	
For Total Drop of 4 Per Cent[a]								
Power:								
Branches	1	...	...	2.2	2.3	4.4	5.5	In accordance with recommendations of the National Electrical Code
Mains and feeders combined	3	...	...	6.6	6.9	13.2	16.5	
Total	4	...	...	8.8	9.2	17.6	22.0	

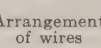
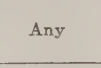
[a] Gives especially good operating conditions.

38. Graph for Computing Conductor Sizes for Circuits According to Voltage Drop

39. Effect of inductance can be neglected unless the size of wire exceeds the following values:

Type of load	Size of wire with following spacings										
	In conduit	2½ in.	4 in.	5 in.	6 in.	8 in.	12 in.	18 in.	24 in.	36 in.	48 in.
Incandescent lamps—60 cycles	4/0	2/0	1/0	1/0	1	1	2	2	2	3	3
Incandescent lamps—25 cycles	600,000	400,000	300,000	4/0	4/0	4/0	3/0	3/0	3/0	3/0	2/0
Motors—60 cycles	1	3	4	4	5	5	5				
Motors—25 cycles	4/0	00	0	0	0	1	1	2	2	2	3

40. Effective Spacings of Wires to Use for Different Systems

System	Arrangement of wires	Effective spacing that should be used with Mershon diagram or table of ratio of reactance to resistance
Single-phase, three-wire	Any	Use spacing between outside wires
Two-phase, any number of wires	Any	Use a spacing equal to average distance between centers of wires of the same phase
Three-phase		Effective spacing = $\sqrt[3]{ABC}$ when wires are transposed so that each wire occupies each position for approximately one-third of the length of the line
		Effective spacing = $\sqrt[3]{ABC}$ when wires are transposed so that each wire occupies each position for approximately one-third of the length of the line
		Effective spacing = $1.26A$ when wires are transposed so that each wire occupies each position for approximately one-third of the length of the line The position of the neutral in a four-wire system does not affect the spacing

41. Approximate Power Factors of Apparatus

Type of Apparatus	Power Factor
Incandescent lamps and heaters	1.0
Fluorescent lamps and mercury-vapor lamps[a]	0.5–0.95
Induction motors:[b]	
1 hp	0.67
2 hp	0.73
3 hp	0.80
5 hp	0.83
7½–25 hp	0.86
30–50 hp	0.89
60–125 hp	0.92
150–200 hp	0.93
Synchronous motors	0.8 to 1.0 leading

NOTE.—All power factors less than unity are lagging except for synchronous motors.

[a] For more accurate information refer to Div. 10.

[b] The values of power factor for induction motors are average values when the motors are operating at 75 per cent of rated load.

42. 60-Cycle Ratios—Reactance to Resistance

Type	B. & S. no.	Area cir. mils	Ratios for distance between wires (see Sec. 40)															
			In conduit	2½ in.	3 in.	4 in.	5 in.	6 in.	8 in.	12 in.	18 in.	2 ft.	3 ft.	4 ft.	5 ft.	6 ft.	7 ft.	8 ft.
Stranded	...	2,000,000	....	....	7.07	8.23	9.16	9.90	11.10	12.80	14.40	15.70	17.30	18.50	19.20	20.10	20.80	21.40
	...	1,800,000	....	....	6.52	7.58	8.46	9.15	10.20	11.70	13.20	14.30	15.80	17.00	17.70	18.40	19.00	19.40
	...	1,700,000	....	....	6.30	7.30	8.05	8.72	9.70	11.20	12.60	13.60	15.00	16.10	16.90	17.40	18.00	18.50
	...	1,600,000	....	....	5.97	6.96	7.67	8.30	9.22	10.60	11.90	12.90	14.20	15.20	16.00	16.40	17.00	17.50
	...	1,500,000	....	....	5.70	6.62	7.25	7.90	8.75	9.95	11.30	12.10	13.40	14.30	15.00	15.60	16.00	16.40
	...	1,400,000	....	....	5.40	6.26	6.90	7.40	8.28	9.43	10.60	11.50	12.60	13.50	14.10	14.70	15.20	15.50
	...	1,200,000	....	....	4.84	5.52	6.10	6.55	7.28	8.26	9.20	10.00	11.00	11.70	12.20	12.80	13.10	13.40
	...	1,100,000	....	....	4.51	5.20	5.70	6.11	6.75	7.70	8.60	9.25	10.20	10.80	11.40	11.80	12.10	12.40
	...	1,000,000	2.89	3.66	4.22	4.81	5.29	5.65	6.25	7.10	7.92	8.52	9.37	9.96	10.40	10.80	11.10	11.40
	...	950,000	....	....	4.05	4.60	5.05	5.42	6.00	6.80	7.55	8.12	8.95	9.50	9.95	10.30	10.60	10.90
	...	900,000	2.69	3.39	3.92	4.43	4.87	5.20	5.75	6.50	7.24	7.82	8.50	9.10	9.52	9.82	10.10	10.40
	...	850,000	....	....	3.76	4.24	4.65	4.97	5.46	6.20	6.90	7.40	8.15	8.65	9.03	9.33	9.65	9.85
	...	800,000	2.49	3.12	3.55	4.03	4.42	4.70	5.17	5.83	6.55	7.00	7.65	8.15	8.50	8.80	9.10	9.30
	...	750,000	....	....	3.39	3.84	4.18	4.48	4.91	5.55	6.18	6.63	7.25	7.70	8.05	8.35	8.60	8.78
	...	700,000	2.06	2.84	3.21	3.66	3.98	4.25	4.65	5.23	5.82	6.25	6.83	7.25	7.60	7.85	8.10	8.27
	...	650,000	....	....	3.06	3.42	3.73	3.98	4.35	4.90	5.46	5.85	6.40	6.77	7.10	7.32	7.55	7.73
	...	600,000	1.85	2.52	2.85	3.21	3.47	3.70	4.07	4.55	5.05	5.42	5.93	6.30	6.55	6.80	6.98	7.15
	...	550,000	....	....	2.66	2.98	3.22	3.44	3.76	4.22	4.68	5.00	5.45	5.80	6.05	6.27	6.45	6.60
	...	500,000	1.75	2.30	2.48	2.78	2.99	3.20	3.51	3.92	4.35	4.63	5.05	5.35	5.60	5.78	5.90	6.08
	...	450,000	....	....	2.26	2.52	2.74	2.90	3.16	3.54	3.90	4.18	4.55	4.84	5.04	5.20	5.32	5.47

60 Cycle Ratios—Reactance to Resistance *(Continued)*

Type	B. & S. no.	Area cir. mils	Ratios for distance between wires (see Sec. 40)															
			In conduit	2½ in.	3 in.	4 in.	5 in.	6 in.	8 in.	12 in.	18 in.	2 ft.	3 ft.	4 ft.	5 ft.	6 ft.	7 ft.	8 ft.
Stranded	...	400,000	1.49	1.93	2.07	2.30	2.48	2.64	2.88	3.21	3.54	3.77	4.12	4.35	4.55	4.68	4.82	4.91
	...	350,000	....	....	1.87	2.08	2.23	2.37	2.58	2.87	3.17	3.38	3.68	3.88	4.05	4.17	4.30	4.39
	...	300,000	1.01	1.54	1.63	1.81	1.95	2.06	2.23	2.49	2.74	2.92	3.16	3.34	3.48	3.60	3.70	3.77
	...	250,000	....	....	1.41	1.56	1.67	1.76	1.91	2.13	2.34	2.50	2.70	2.85	2.97	3.06	3.13	3.20
	4/0	211,600	0.76	1.17	1.23	1.36	1.46	1.54	1.66	1.84	2.02	2.15	2.33	2.46	2.55	2.63	2.69	2.76
	3/0	167,772	0.64	0.97	1.02	1.11	1.20	1.26	1.36	1.50	1.64	1.74	1.88	1.98	2.06	2.12	2.16	2.22
	2/0	133,079	0.54	0.80	0.84	0.91	0.98	1.03	1.11	1.22	1.33	1.41	1.52	1.60	1.66	1.71	1.75	1.79
	1/0	105,560	0.38	0.66	0.69	0.75	0.80	0.84	0.90	1.00	1.08	1.15	1.23	1.30	1.35	1.39	1.42	1.45
	1	83,694	0.32	0.54	0.57	0.62	0.66	0.70	0.74	0.81	0.88	0.94	1.00	1.06	1.10	1.13	1.15	1.17
	2	66,358	0.26	0.45	0.47	0.50	0.53	0.56	0.60	0.65	0.71	0.75	0.81	0.85	0.88	0.90	0.92	0.95
	3	52,624	0.22	0.37	0.38	0.41	0.44	0.45	0.48	0.53	0.58	0.60	0.65	0.68	0.70	0.72	0.74	0.75
	4	41,738	0.15	0.30	0.31	0.34	0.35	0.37	0.40	0.43	0.47	0.49	0.53	0.55	0.57	0.59	0.60	0.61
	5	33,088	0.14	0.25	0.25	0.27	0.29	0.30	0.32	0.35	0.37	0.40	0.42	0.44	0.46	0.47	0.48	0.49
Solid	4/0	211,600	0.77	1.18	1.25	1.38	1.48	1.56	1.69	1.87	2.06	2.18	2.37	2.50	2.60	2.68	2.72	2.81
	3/0	167,772	0.65	0.98	1.04	1.14	1.22	1.29	1.39	1.53	1.68	1.78	1.92	2.04	2.10	2.17	2.20	2.27
	2/0	133,079	0.55	0.81	0.85	0.94	1.00	1.05	1.13	1.25	1.36	1.44	1.55	1.64	1.70	1.75	1.79	1.84
	1/0	105,560	0.39	0.67	0.70	0.77	0.82	0.86	0.92	1.01	1.11	1.17	1.26	1.32	1.37	1.41	1.45	1.48
	1	83,694	0.33	0.55	0.59	0.63	0.67	0.71	0.76	0.83	0.90	0.95	1.03	1.08	1.12	1.15	1.17	1.20
	2	66,358	0.27	0.46	0.48	0.52	0.55	0.57	0.61	0.67	0.73	0.77	0.83	0.87	0.89	0.92	0.94	0.96
	3	52,624	0.23	0.38	0.39	0.42	0.44	0.46	0.49	0.54	0.58	0.61	0.66	0.69	0.71	0.74	0.75	0.77
	4	41,738	0.16	0.31	0.32	0.34	0.36	0.38	0.40	0.44	0.48	0.50	0.53	0.56	0.58	0.60	0.61	0.62
	5	33,088	0.15	0.25	0.26	0.28	0.30	0.31	0.33	0.36	0.39	0.40	0.43	0.45	0.47	0.48	0.50	0.50

43. 25-cycle Ratios—Reactance to Resistance

Type	B. & S. No.	Area, cir. mils	Distance between wires (see Sec. 40)													
			In conduit	2½ in.	3 in.	4 in.	5 in.	6 in.	8 in.	12 in.	18 in.	2 ft.	3 ft.	4 ft.	5 ft.	6 ft.	7 ft.	8 ft.
			Ratio															
Stranded	...	2,000,000	....	....	2.93	3.42	3.82	4.12	4.60	5.32	5.98	6.52	7.20	7.68	8.00	8.35	8.67	8.92
	...	1,800,000	....	....	2.74	3.17	3.50	3.79	4.25	4.86	5.47	5.95	6.60	7.02	7.40	7.64	7.88	8.06
	...	1,700,000	....	....	2.62	3.02	3.34	3.64	4.04	4.65	5.24	5.67	6.25	6.70	7.02	7.27	7.50	7.70
	...	1,600,000	....	....	2.48	2.89	3.19	3.46	3.84	4.38	4.93	5.35	5.90	6.30	6.65	6.85	7.10	7.25
	...	1,500,000	....	....	2.38	2.76	3.04	3.27	3.63	4.15	4.68	5.05	5.60	5.96	6.24	6.48	6.68	6.83
	...	1,400,000	....	....	2.27	2.60	2.87	3.08	3.44	3.92	4.42	4.77	5.25	5.60	5.88	6.10	6.30	6.43
	...	1,200,000	....	....	2.02	2.31	2.54	2.72	3.02	3.44	3.85	4.18	4.58	4.87	5.12	5.32	5.45	5.60
	...	1,100,000	....	....	1.87	2.15	2.38	2.55	2.81	3.20	3.56	3.85	4.24	4.50	4.75	4.90	5.03	5.17
	...	1,000,000	1.20	1.53	1.78	2.00	2.20	2.36	2.60	2.95	3.31	3.55	3.91	4.16	4.35	4.48	4.63	4.76
	...	950,000	....	....	1.70	1.91	2.10	2.25	2.49	2.83	3.16	3.38	3.70	3.96	4.14	4.27	4.40	4.53
	...	900,000	1.12	1.42	1.63	1.85	2.03	2.17	2.38	2.71	3.02	3.25	3.54	3.79	3.97	4.08	4.20	4.32
	...	850,000	....	....	1.57	1.77	1.95	2.08	2.28	2.57	2.86	3.08	3.39	3.60	3.75	3.89	4.01	4.10
	...	800,000	1.03	1.30	1.48	1.69	1.84	1.96	2.15	2.42	2.72	2.91	3.17	3.38	3.54	3.65	3.77	3.87
	...	750,000	....	....	1.41	1.60	1.74	1.87	2.05	2.32	2.57	2.77	3.02	3.21	3.36	3.47	3.57	3.66
	...	700,000	0.86	1.18	1.34	1.52	1.65	1.77	1.93	2.18	2.42	2.60	2.85	3.02	3.16	3.27	3.36	3.44
	...	650,000	....	....	1.27	1.43	1.56	1.66	1.81	2.04	2.28	2.42	2.66	2.83	2.96	3.04	3.14	3.22
	...	600,000	0.77	1.05	1.19	1.34	1.44	1.55	1.70	1.90	2.11	2.25	2.47	2.62	2.72	2.82	2.90	2.98
	...	550,000	....	....	1.10	1.24	1.34	1.43	1.56	1.76	1.94	2.08	2.27	2.41	2.51	2.62	2.68	2.74
	...	500,000	0.73	0.96	1.03	1.15	1.25	1.33	1.46	1.63	1.81	1.93	2.12	2.23	2.33	2.42	2.46	2.53
	...	450,000	....	....	0.95	1.05	1.14	1.21	1.32	1.47	1.63	1.75	1.90	2.01	2.09	2.16	2.22	2.28

25-cycle Ratios—Reactance to Resistance (*Continued*)

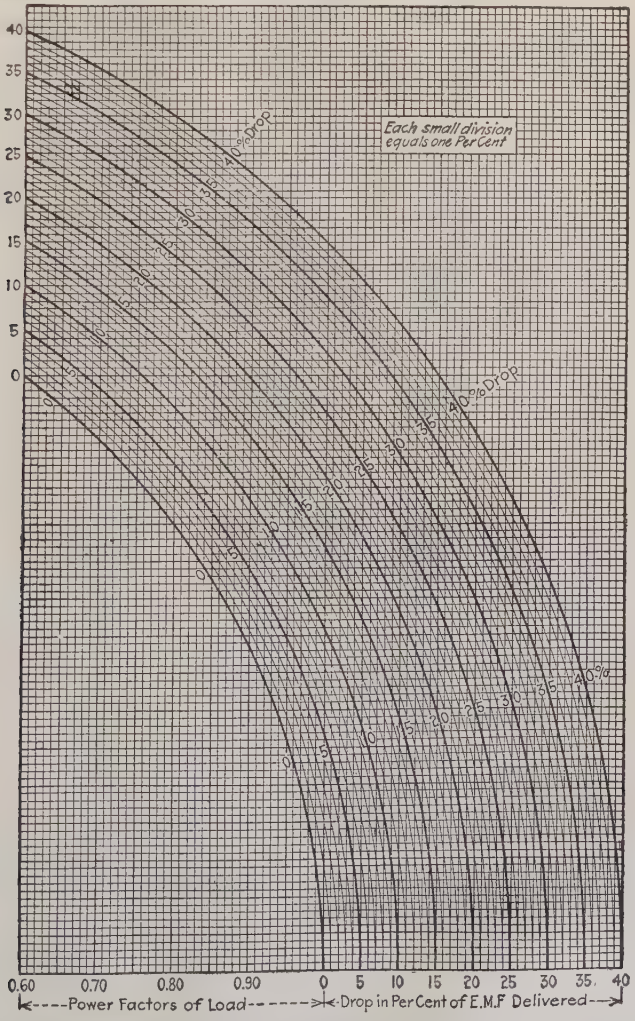
Type	B. & S. No.	Area, cir. mils	Distance between wires (see Sec. 40)															
			In conduit	2½ in.	3 in.	4 in.	5 in.	6 in.	8 in.	12 in.	18 in.	2 ft.	3 ft.	4 ft.	5 ft.	6 ft.	7 ft.	8 ft.
			Ratio															
Stranded	...	400,000	0.62	0.81	0.86	0.96	1.03	1.10	1.20	1.33	1.47	1.57	1.72	1.81	1.89	1.95	2.01	2.05
	...	350,000	....	....	0.78	0.86	0.93	0.99	1.07	1.20	1.32	1.41	1.53	1.62	1.68	1.75	1.80	1.83
	...	300,000	0.42	0.64	0.68	0.76	0.81	0.86	0.93	1.04	1.15	1.22	1.32	1.40	1.45	1.50	1.54	1.57
	...	250,000	....	....	0.59	0.65	0.69	0.74	0.80	0.89	0.97	1.04	1.12	1.19	1.23	1.27	1.30	1.34
	4/0	211,600	0.32	0.49	0.51	0.57	0.61	0.64	0.69	0.77	0.84	0.90	0.97	1.02	1.06	1.09	1.12	1.15
	3/0	167,772	0.27	0.40	0.42	0.46	0.50	0.52	0.56	0.62	0.68	0.73	0.79	0.83	0.86	0.88	0.90	0.93
	2/0	133,079	0.23	0.33	0.35	0.38	0.41	0.43	0.46	0.51	0.55	0.59	0.63	0.66	0.69	0.71	0.73	0.75
	1/0	105,560	0.16	0.28	0.29	0.31	0.33	0.35	0.38	0.41	0.45	0.48	0.51	0.54	0.56	0.58	0.59	0.60
	1	83,694	0.13	0.23	0.24	0.26	0.28	0.29	0.31	0.34	0.37	0.39	0.42	0.44	0.46	0.47	0.48	0.49
	2	66,358	0.11	0.19	0.19	0.21	0.22	0.24	0.25	0.27	0.30	0.31	0.34	0.35	0.36	0.38	0.38	0.39
	3	52,624	0.09	0.15	0.16	0.17	0.18	0.19	0.20	0.22	0.24	0.25	0.27	0.28	0.29	0.30	0.31	0.31
	4	41,738	0.06	0.12	0.13	0.14	0.15	0.15	0.16	0.18	0.19	0.20	0.22	0.23	0.24	0.24	0.25	0.25
	5	33,088	0.06	0.10	0.10	0.11	0.12	0.12	0.13	0.14	0.16	0.16	0.18	0.18	0.19	0.19	0.20	0.20
Solid	4/0	211,600	0.33	0.50	0.52	0.58	0.62	0.65	0.71	0.78	0.86	0.91	0.99	1.04	1.08	1.12	1.14	1.17
	3/0	167,772	0.28	0.41	0.43	0.48	0.51	0.54	0.58	0.64	0.70	0.74	0.80	0.84	0.88	0.90	0.92	0.95
	2/0	133,079	0.24	0.34	0.36	0.39	0.42	0.44	0.47	0.52	0.57	0.60	0.65	0.68	0.71	0.73	0.74	0.76
	1/0	105,560	0.17	0.29	0.29	0.32	0.34	0.36	0.38	0.42	0.46	0.49	0.52	0.55	0.57	0.59	0.60	0.72
	1	83,694	0.14	0.24	0.24	0.26	0.28	0.29	0.31	0.35	0.38	0.40	0.43	0.45	0.47	0.48	0.49	0.50
	2	66,358	0.12	0.20	0.20	0.22	0.23	0.24	0.25	0.28	0.30	0.32	0.35	0.36	0.37	0.39	0.39	0.40
	3	52,624	0.10	0.16	0.16	0.17	0.18	0.19	0.20	0.22	0.24	0.25	0.27	0.29	0.30	0.31	0.31	0.32
	4	41,738	0.07	0.13	0.13	0.14	0.15	0.16	0.17	0.18	0.20	0.21	0.22	0.23	0.24	0.25	0.25	0.26
	5	33,088	0.07	0.11	0.11	0.13	0.12	0.13	0.14	0.15	0.16	0.17	0.18	0.19	0.20	0.20	0.21	0.21

44. Alternating-current Drop Factors

Ratio of reactance to resistance	Power factor							
	1.00	0.95	0.90	0.85	0.80	0.70	0.60	0.40
	Drop factor							
0.1	1.00	1.00	1.00	0.94	0.88	0.80	0.70	0.6
0.2	1.00	1.01	1.01	0.98	0.92	0.86	0.82	0.6
0.3	1.00	1.05	1.05	1.02	0.99	0.93	0.89	0.7
0.4	1.00	1.08	1.10	1.08	1.04	1.00	0.93	0.8
0.5	1.00	1.11	1.14	1.13	1.10	1.07	1.01	0.9
0.6	1.01	1.15	1.18	1.19	1.15	1.14	1.09	1.0
0.7	1.02	1.18	1.23	1.24	1.21	1.20	1.17	1.1
0.8	1.02	1.21	1.28	1.29	1.28	1.27	1.24	1.2
0.9	1.03	1.25	1.33	1.34	1.34	1.35	1.32	1.2
1.0	1.04	1.28	1.37	1.39	1.40	1.41	1.39	1.3
1.1	1.05	1.32	1.41	1.44	1.45	1.48	1.47	1.4
1.2	1.06	1.35	1.46	1.50	1.51	1.55	1.54	1.5
1.3	1.07	1.39	1.51	1.55	1.57	1.62	1.63	1.6
1.4	1.08	1.43	1.55	1.61	1.64	1.70	1.71	1.7
.5	1.10	1.47	1.60	1.67	1.70	1.77	1.80	1.8
1.6	1.10	1.51	1.65	1.74	1.77	1.85	1.87	1.9
1.7	1.13	1.55	1.70	1.79	1.84	1.92	1.95	1.9
1.8	1.15	1.59	1.76	1.85	1.91	1.99	2.04	2.0
1.9	1.17	1.63	1.82	1.91	1.98	2.06	2.11	2.1
2.0	1.18	1.68	1.87	1.96	2.04	2.14	2.19	2.2
2.1	1.20	1.72	1.92	2.03	2.10	2.21	2.28	2.3
2.2	1.22	1.77	1.98	2.09	2.17	2.29	2.37	2.4
2.3	1.23	1.82	2.03	2.15	2.23	2.37	2.45	2.5
2.4	1.25	1.87	2.09	2.22	2.30	2.44	2.53	2.6
2.5	1.27	1.91	2.14	2.28	2.37	2.52	2.60	2.7
2.6	1.30	1.95	2.20	2.34	2.44	2.60	2.67	2.8
2.7	1.32	1.99	2.26	2.41	2.51	2.68	2.74	2.9
2.8	1.35	2.05	2.32	2.47	2.57	2.76	2.82	3.0
2.9	1.37	2.10	2.39	2.54	2.64	2.83	2.91	3.1
3.0	1.40	2.15	2.45	2.60	2.72	2.90	3.00	3.2
3.1	1.42	2.20	2.51	2.66	2.80	2.97	3.10	3.3
3.2	1.45	2.26	2.57	2.73	2.87	3.05	3.20	3.3
3.3	1.48	2.31	2.63	2.80	2.93	3.12	3.30	3.4
3.4	1.51	2.36	2.69	2.87	3.00	3.20	3.39	3.5
3.5	1.53	2.42	2.74	2.94	3.08	3.27	3.48	3.6
3.6	1.57	2.47	2.80	3.00	3.15	3.35	3.56	3.7
3.7	1.60	2.52	2.86	3.07	3.23	3.43	3.65	3.8

45. The Mershon Diagram

See Div. **3** for directions as to its use and application. (The side of each small square equals 1 per cent; percentage of resistance is measured horizontally and percentage of reactance vertically.)



See for directions as to its use and application. (The side of each small square equals 1 per cent; percentage of resistance is measured horizontally and percentage of reactance vertically.)

46. Average D-c Resistances and Correction Factors for A-c Resistances and Reactances for Copper Conductors

Size, A.w.g. or cir. mils	D-c resistance, ohms per 1000 ft.			60-cycle correction factors[b]			
				Single conductor, A-c resistance[c]		Three conductors	
	At 50°C.[a]	At 60°C.[a]	At 70°C.[a]	Standard strand	Annular	A-c resistance	Reactance (for cable with magnetic binder)
8	0.705	0.735	0.765	1.00	....	1.00	1.26
6	0.445	0.464	0.482	1.00	....	1.00	1.26
4	0.279	0.292	0.303	1.00	....	1.00	1.26
2	0.176	0.184	0.191	1.00	....	1.01	1.26
1	0.140	0.146	0.152	1.00	....	1.01	1.26
1/0	0.117	0.115	0.120	1.00	....	1.02	1.26
2/0	0.0877	0.0915	0.0952	1.00	....	1.03	1.26
3/0	0.0696	0.0725	0.0755	1.00	....	1.04	1.26
4/0	0.0552	0.0575	0.0598	1.00	....	1.05	1.26
250,000	0.0467	0.0486	0.0506	1.01	....	1.06	1.26
300,000	0.0390	0.0406	0.0423	1.01	....	1.07	1.26
350,000	0.0336	0.0348	0.0362	1.01	....	1.08	1.26
400,000	0.0292	0.0304	0.0317	1.02	....	1.10	1.25
500,000	0.0234	0.0244	0.0254	1.02	....	1.13	1.25
600,000	0.0195	0.0203	0.0211	1.03	....	1.16	1.24
700,000	0.0167	0.0174	0.0181	1.03	....	1.19	1.24
750,000	0.0156	0.0162	0.0169	1.04	1.02	1.21	1.23
800,000	0.0147	0.0153	0.0159	1.05	1.02		
1,000,000	0.0117	0.0122	0.0127	1.07	1.03		
1,250,000	0.0093	0.0097	0.0101	1.11	1.03		
1,500,000	0.0078	0.0081	0.00842	1.15	1.04		
1,750,000	0.00667	0.00695	0.00724	1.19	1.05		
2,000,000	0.00583	0.00607	0.00632	1.24	1.06		
2,500,000	0.00467	0.00486	0.00506	....	1.11		

[a] Temperature correction is 0.39 per cent per degree centigrade (positive for higher temperatures, negative for lower temperatures).

[b] These are multiplying factors.

[c] Allows for skin effect only.

47. Direct-current Resistance of Solid Copper Wire

Size A.w.g.	Max. resistance, ohms per 1,000 ft. at 68°F.			
	Soft or annealed	Medium hard	Hard drawn	Tinned, soft drawn
4/0	0.04993	0.05019	0.05045	
3/0	0.06296	0.06329	0.06361	
2/0	0.07939	0.07980	0.08021	
1/0	0.1001	0.1006	0.1011	
1	0.1262	0.1282	0.1287	0.1275
2	0.1592	0.1617	0.1625	0.1608
3	0.2007	0.2038	0.2049	0.2028
4	0.2531	0.2570	0.2584	0.2557
5	0.3192	0.3241	0.3258	0.3225
6	0.4025	0.4087	0.4108	0.4066
7	0.5075	0.5154	0.5181	0.5127
8	0.6400	0.6499	0.6533	0.6465
9	0.8070	0.8195	0.8238	0.8153
10	1.018	1.033	1.039	1.039
11	1.283	1.303	1.310	1.310
12	1.618	1.643	1.652	1.652
13	2.040	2.072	2.083	2.083
14	2.573	2.613	2.626	2.626
15	3.244	3.295	3.312	3.312
16	4.091	4.154	4.176	4.176
17	5.158	5.239	5.266	5.266
18	6.505	6.606	6.640	6.640
19	8.202	8.330	8.373	8.373
20	10.34	10.50	10.56	10.56
21	13.04	13.24	13.31	13.31
22	16.45	16.70	16.79	16.79
23	20.74	21.06	21.17	21.17
24	26.15	26.56	26.69	27.26
25	32.97	33.49	33.66	34.37
26	41.58	42.23	42.44	43.34
27	52.43	53.25	53.52	54.66
28	66.11	67.14	67.49	68.92
29	83.37	84.66	85.10	87.85
30	105.1	106.8	107.3	110.8
31	132.6	134.6	135.3	139.7
32	167.2	169.8	170.6	176.1
33	210.8	214.1	215.2	222.1
34	265.8	269.9	271.3	280.1
35	335.2	340.4	342.1	353.2
36	422.6	429.2	431.4	445.4
37	532.9	541.2	544.0	561.6
38	672.0	682.4	686	708.1
39	847.4	860.5	865	893
40	1069	1085	1091	1126
41	1347	1368	1375	
42	1699	1725	1734	
43	2142	2176	2187	
44	2702	2743	2758	
45	3406	3459	3477	

The above resistances are maximum values for nominal diameters based upon A.S.T.M. specification resistivities, as follows:

Conductor	Lb. per mile-ohm	Equivalent I.A.C.S. per cent conductivity
Soft or annealed (A.S.T.M. Spec. B 3)	891.58	98.16
Medium hard (A.S.T.M. Spec. B 2):		
Diameter 0.460 in.—0.325 in. (No. 4/0—No. 1/0 A.w.g.)	896.15	97.66
Diameter 0.324 in.—0.040 in. (No. 1—No. 18 A.w.g.)	905.44	96.66
Hard drawn (A.S.T.M. Spec. B 1):		
Diameter 0.460 in.—0.325 in. (No. 4/0—No. 1/0 A.w.g.)	900.77	97.16
Diameter 0.324 in.—0.040 in. (No. 1—No. 18 A.w.g.)	910.15	96.16

For wire sizes smaller than No. 18 A.w.g. in medium-hard and hard-drawn tempers: No A.S.T.M. requirements; resistances for these sizes in above table based on 905.44 lb. per mile-ohm (96.66 per cent conductivity) for medium hard wire, and 910.15 lb. per mile-ohm (96.16 per cent conductivity) for hard-drawn wire.

The above data are approximate and subject to normal manufacturing tolerances.

48. Direct-current Resistance of Stranded Copper Wire

Size		Resistance, ohms per 1,000 ft. at 68°F.			
A.w.g.	Circular mils	Soft or annealed	Medium hard	Hard drawn	Tinned, soft drawn
...	5,000,000	0.002219			
...	4,500,000	0.002465			
...	4,000,000	0.002747			
...	3,500,000	0.003139			
...	3,000,000	0.003628			
...	2,500,000	0.004353			
...	2,000,000	0.005388	.....	.....	0.005444
...	1,750,000	0.006158	.....	.....	0.006221
...	1,500,000	0.007185	.....	.....	0.007258
...	1,250,000	0.008622	.....	.....	0.008710
...	1,000,000	0.01078	0.01094	0.01100	0.01089
...	900,000	0.01197	0.01216	0.01222	0.01210
...	800,000	0.01347	0.01368	0.01375	0.01361
...	750,000	0.01438	0.01459	0.01467	0.01452
...	700,000	0.01540	0.01563	0.01572	0.01555
...	600,000	0.01796	0.01824	0.01834	0.01833
...	500,000	0.02155	0.02189	0.02200	0.02178
...	450,000	0.02395	0.02432	0.02445	0.02419
...	400,000	0.02684	0.02736	0.02750	0.02722
...	350,000	0.03079	0.03127	0.03143	0.03143
...	300,000	0.03592	0.03648	0.03667	0.03667
...	250,000	0.04311	0.04378	0.04400	0.04400
4/0	211,600	0.05093	0.05172	0.05199	0.05145
3/0	167,800	0.06422	0.06522	0.06556	0.06556
2/0	133,100	0.08097	0.08223	0.08256	0.08266
1/0	105,500	0.1021	0.1037	0.1043	0.1042
1	83,690	0.1288	0.1308	0.1315	0.1314
2	66,370	0.1624	0.1649	0.1658	0.1657
3	52,630	0.2047	0.2059	0.2070	0.2090
4	41,740	0.2582	0.2596	0.2610	0.2635
5	33,100	0.3256	0.3274	0.3291	0.3323
6	26,250	0.4105	0.4128	0.4149	0.4191
7	20,820	0.5176	.....	.....	0.5284
8	16,510	0.6528	.....	.....	0.6663
9	13,090	0.8233	.....	.....	0.8402
10	10,380	1.038	.....	.....	1.060
12	6,530	1.650	.....	.....	1.685
14	4,107	2.624	.....	.....	2.679
16	2,583	4.172	.....	.....	4.350
18	1,624	6.636	.....	.....	6.917
20	1,022	10.54	.....	.....	11.00

Resistances: Maximum values for nominal diameters based upon A.S.T.M. Spec. B 3 resistivity of 891.58 lb. per mile-ohm (equivalent to 98.16 per cent I.A.C.S. conductivity), increased as follows for stranding.

Size, Cir. Mils or A.w.g.	Per Cent of Increase of Resistance
5,000,000–4,500,000	5
4,000,000–3,500,000	4
3,000,000–2,500,000	3
2,000,000– 250,000	2
4/0– 20	2

49. Skin-effect Ratios for Concentric-stranded and Annular Copper Conductors

Size, cir. mils	Skin-effect ratio			
	Concentric stranded		Annular conductor	
	25 cycles	60 cycles	25 cycles	60 cycles
250,000	.....	1.005		
300,000	.....	1.006		
350,000	.....	1.009		
400,000	.....	1.011		
450,000	.....	1.014		
500,000	.....	1.018		
550,000	.....	1.021		
600,000	1.005	1.025		
650,000	1.005	1.029		
700,000	1.006	1.034		
750,000	1.007	1.039	1.004	1.021
800,000	1.008	1.044	1.004	1.020
850,000	1.009	1.049		
900,000	1.010	1.055	1.005	1.025
950,000	1.011	1.061		
1,000,000	1.012	1.067	1.006	1.031
1,250,000	1.019	1.102	1.007	1.034
1,500,000	1.027	1.142	1.007	1.037
1,750,000	1.037	1.185	1.008	1.043
2,000,000	1.048	1.233	1.009	1.045
2,250,000	1.059	1.276		
2,500,000	1.071	1.326	1.012	1.066
3,000,000	1.100	1.424	1.019	1.105
3,500,000	1.130	1.513	1.020	1.110
4,000,000	1.165	1.605	1.021	1.116
4,500,000	1.200	1.685	1.022	1.118
5,000,000	1.237	1.765	1.023	1.121

50. Skin-effect Ratio for Tubular Copper Conductors

This table gives the conductor diameter in inches d, and the 60-cycle, skin-effect ratio or ratio of a-c to d-c resistance, both for the ordinary form of stranding (inside diameter = 0) and for tubular conductors.

Size, cir. mils	Inside diam. of tubular conductor, in.							
	0		0.25		0.50		0.75	
	d	Ratio	d	Ratio	d	Ratio	d	Ratio
3,000,000	1.998	1.439	2.02	1.39	2.08	1.36	2.15	1.29
2,500,000	1.825	1.336	1.87	1.28	1.91	1.24	2.00	1.20
2,000,000	1.631	1.239	1.67	1.20	1.72	1.17	1.80	1.12
1,500,000	1.412	1.145	1.45	1.12	1.52	1.09	1.63	1.06
1,000,000	1.152	1.068	1.19	1.05	1.25	1.03	1.39	1.02
800,000	1.031	1.046	1.07	1.04	1.16	1.02	1.28	1.01
600,000	.893	1.026	.94	1.02	1.04	1.01		
500,000	.814	1.018	.86	1.01	.97	1.01		
400,000	.728	1.012	.78	1.01				
300,000	.630	1.006						

Size, cir. mils	Inside diam. of tubular conductor, in.							
	1.00		1.25		1.50		2.00	
	d	Ratio	d	Ratio	d	Ratio	d	Ratio
3,000,000	2.27	1.23	2.39	1.19	2.54	1.15	2.87	1.08
2,500,000	2.12	1.16	2.25	1.12	2.40	1.09	2.75	1.05
2,000,000	1.94	1.09	2.09	1.06	2.25	1.05	2.61	1.02
1,500,000	1.75	1.04	1.91	1.03	2.07	1.02	2.47	1.01
1,000,000	1.53	1.01	1.72	1.01				
800,000	1.45	1.01						

51. Average Resistance for All-steel Conductors

Size and type of conductor	D-c resistance, ohms per 1,000 ft. at 68°F.	A-c, 60-cycle resistance at various loadings, ohms per 1,000 ft. at 68°F.				
		1 amp.	5 amps.	10 amps.	15 amps.	20 amps.
Type S:						
4 B.w.g., solid	1.5	1.6	1.7	1.9	2.1	2.4
6 B.w.g., solid	2.1	2.2	2.2	2.3	2.6	
8 B.w.g., solid	3.2	3.3	3.4	3.7		
Type S-3:						
4 B.w.g., three-wire	1.5	1.6	1.6	1.6	1.7	1.7
6 B.w.g., three-wire	2.1	2.2	2.2	2.2	2.3	
8 B.w.g., three-wire	3.2	3.3	3.3	3.4		

52. Average Resistance for Copper-steel Conductors

Size, A.w.g.	D-c resistance, ohms	A-c resistance, ohms
2	0.160	0.17
4	0.256	0.27
6	0.406	0.41
8	0.646	0.66
10	1.050	1.06
12	1.660	1.68

53. Average D-c Resistance for Copperweld Conductors

Conductor

SOLID CONDUCTORS:

30 per cent conductivity—multiply resistance of solid copper wire of same size by 3.33

40 per cent conductivity—multiply resistance of solid copper wire of same size by 2.5

STRANDED CONDUCTORS:

30 per cent conductivity—multiply resistance of solid copper wire of same size as each strand by the product of number of strands times 3.4

40 per cent conductivity—multiply resistance of solid copper wire of same size as each strand by the product of number of strands times 2.55

COMPOSITE CONDUCTORS—refer to Table 107 of Div. 2

54. Resistance of Aluminum Cable, Steel-reinforced

Size, cir. mils or A.w.g. (B. & S.) aluminum	No. of layers of alum. over steel core	No. of wires		Copper equiv., cir. mils or A.w.g., based on copper 97%, alum. 61%	D-c resistance, ohms per mile at 0 amp. and 25°C.	A-c resistance, ohms per mile of single conductor at 25°C.														
						200 amp. per sq. in.			400 amp. per sq. in.			800 amp. per sq. in.			1,000 amp. per sq. in.			1,400 amp. per sq. in.		
		Alum.	Steel			25 cycles	50 cycles	60 cycles	25 cycles	50 cycles	60 cycles	25 cycles	50 cycles	60 cycles	25 cycles	50 cycles	60 cycles	25 cycles	50 cycles	60 cycles
1,590,000	3	54	19	1,000,000	0.0587	0.0589	0.0592	0.0594	0.0590	0.0595	0.0598	0.0595	0.0611	0.0619	0.0600	0.0625	0.0638	0.0615	0.0670	0.0698
1,510,500	3	54	19	950,000	0.0618	0.0620	0.0623	0.0625	0.0621	0.0626	0.0629	0.0626	0.0642	0.0650	0.0630	0.0655	0.0668	0.0545	0.0698	0.0726
1,431,000	3	54	19	900,000	0.0652	0.0654	0.0658	0.0659	0.0655	0.0661	0.0663	0.0660	0.0676	0.0684	0.0665	0.0690	0.0703	0.0678	0.0730	0.0756
1,351,500	3	54	19	850,000	0.0691	0.0693	0.0696	0.0698	0.0694	0.0699	0.0702	0.0698	0.0713	0.0721	0.0703	0.0728	0.0740	0.0715	0.0765	0.0790
1,272,000	3	54	19	800,000	0.0734	0.0736	0.0740	0.0742	0.0737	0.0743	0.0746	0.0741	0.0756	0.0764	0.0746	0.0770	0.0782	0.0757	0.0805	0.0829
1,192,500	3	54	19	750,000	0.0783	0.0785	0.0789	0.0791	0.0786	0.0792	0.0795	0.0790	0.0804	0.0812	0.0794	0.0818	0.0830	0.0805	0.0851	0.0874
1,113,000	3	54	19	700,000	0.0839	0.0841	0.0845	0.0848	0.0842	0.0849	0.0852	0.0846	0.0860	0.0867	0.0850	0.0873	0.0885	0.0860	0.0904	0.0927
1,033,500	3	54	7	650,000	0.0903	0.0906	0.0910	0.0913	0.0907	0.0913	0.0917	0.0910	0.0924	0.0931	0.0914	0.0935	0.0945	0.0924	0.0967	0.0988
954,000	3	54	7	600,000	0.0979	0.0980	0.0983	0.0985	0.0981	0.0986	0.0989	0.0986	0.100	0.101	0.0990	0.101	0.102	0.0998	0.104	0.106
900,000	3	54	7	566,000	0.104	0.104	0.104	0.105	0.104	0.105	0.105	0.104	0.106	0.107	0.105	0.107	0.108	0.106	0.110	0.112
874,500	3	54	7	550,000	0.107	0.107	0.107	0.108	0.107	0.108	0.109	0.107	0.109	0.110	0.108	0.110	0.111	0.109	0.113	0.115
795,000	3	54	7	500,000	0.117	0.118	0.119	0.119	0.118	0.119	0.119	0.118	0.119	0.120	0.118	0.120	0.121	0.119	0.123	0.125
795,000	2	26	7	500,000	0.117	0.117	0.117	0.117	0.117	0.117	0.117	0.117	0.117	0.117	0.117	0.117	0.117	0.117	0.117	0.117
795,000	2	30	19	500,000	0.117	0.117	0.117	0.117	0.117	0.117	0.117	0.117	0.117	0.117	0.117	0.117	0.117	0.117	0.117	0.117
715,500	3	54	7	450,000	0.131	0.131	0.132	0.133	0.131	0.132	0.133	0.131	0.133	0.133	0.131	0.133	0.134	0.133	0.137	0.139
715,500	2	26	7	450,000	0.131	0.131	0.131	0.131	0.131	0.131	0.131	0.131	0.131	0.131	0.131	0.131	0.131	0.131	0.131	0.131
715,500	2	30	19	450,000	0.131	0.131	0.131	0.131	0.131	0.131	0.131	0.131	0.131	0.131	0.131	0.131	0.131	0.131	0.131	0.131
666,600	3	54	7	419,000	0.140	0.140	0.141	0.142	0.140	0.141	0.142	0.141	0.143	0.143	0.141	0.143	0.144	0.142	0.146	0.148
636,000	3	54	7	400,000	0.147	0.147	0.148	0.149	0.147	0.148	0.149	0.148	0.149	0.150	0.148	0.151	0.152	0.149	0.153	0.156
636,000	2	26	7	400,000	0.147	0.147	0.147	0.147	0.147	0.147	0.147	0.147	0.147	0.147	0.147	0.147	0.147	0.147	0.147	0.147
636,000	2	30	19	400,000	0.147	0.147	0.147	0.147	0.147	0.147	0.147	0.147	0.147	0.147	0.147	0.147	0.147	0.147	0.147	0.147
605,000	3	54	7	380,500	0.154	0.155	0.155	0.156	0.155	0.156	0.156	0.155	0.157	0.158	0.156	0.159	0.160	0.157	0.161	0.163
605,000	2	26	7	380,500	0.154	0.154	0.154	0.154	0.154	0.154	0.154	0.154	0.154	0.154	0.154	0.154	0.154	0.154	0.154	0.154
556,500	2	26	7	350,000	0.168	0.168	0.168	0.168	0.168	0.168	0.168	0.168	0.168	0.168	0.168	0.168	0.168	0.168	0.168	0.168
556,500	2	30	7	350,000	0.168	0.168	0.168	0.168	0.168	0.168	0.168	0.168	0.168	0.168	0.168	0.168	0.168	0.168	0.168	0.168

500,000	2	30	7	314,500	0.187	0.187	0.187	0.187	0.187	0.187	0.187	0.187	0.187	0.187	0.187	0.187	0.187	0.187	0.187	0.187
477,000	2	26	7	300,000	0.196	0.196	0.196	0.196	0.196	0.196	0.196	0.196	0.196	0.196	0.196	0.196	0.196	0.196	0.196	0.196
477,000	2	30	7	300,000	0.196	0.196	0.196	0.196	0.196	0.196	0.196	0.196	0.196	0.196	0.196	0.196	0.196	0.196	0.196	0.196
397,500	2	26	7	250,000	0.235	0.235	0.235	0.235	0.235	0.235	0.235	0.235	0.235	0.235	0.235	0.235	0.235	0.235	0.235	0.235
397,500	2	30	7	250,000	0.235	0.235	0.235	0.235	0.235	0.235	0.235	0.235	0.235	0.235	0.235	0.235	0.235	0.235	0.235	0.235
336,400	2	26	7	4/0	0.278	0.278	0.278	0.278	0.278	0.278	0.278	0.278	0.278	0.278	0.278	0.278	0.278	0.278	0.278	0.278
336,400	2	30	7	4/0	0.278	0.278	0.278	0.278	0.278	0.278	0.278	0.278	0.278	0.278	0.278	0.278	0.278	0.278	0.278	0.278
300,000	2	26	7	188,700	0.311	0.311	0.311	0.311	0.311	0.311	0.311	0.311	0.311	0.311	0.311	0.311	0.311	0.311	0.311	0.311
300,000	2	30	7	188,700	0.311	0.311	0.311	0.311	0.311	0.311	0.311	0.311	0.311	0.311	0.311	0.311	0.311	0.311	0.311	0.311
266,800	2	26	7	3/0	0.350	0.350	0.350	0.350	0.350	0.350	0.350	0.350	0.350	0.350	0.350	0.350	0.350	0.350	0.350	0.350
266,800	1	6	7	3/0	0.350	0.350	0.351	0.352	0.351	0.353	0.355	0.359	0.378	0.388	0.368	0.406	0.425	0.384	0.454	0.489
4/0	1	6	1	2/0	0.441	0.443	0.445	0.446	0.444	0.450	0.453	0.452	0.474	0.485	0.458	0.493	0.510	0.468	0.521	0.548
3/0	1	6	1	1/0	0.556	0.557	0.560	0.561	0.560	0.566	0.569	0.566	0.584	0.594	0.570	0.597	0.611	0.579	0.624	0.647
2/0	1	6	1	1	0.702	0.703	0.705	0.707	0.704	0.709	0.712	0.708	0.721	0.727	0.711	0.730	0.739	0.720	0.758	0.777
1/0	1	6	1	2	0.885	0.885	0.888	0.889	0.886	0.890	0.892	0.888	0.895	0.899	0.890	0.901	0.907	0.898	0.927	0.941
1	1	6	1	3	1.12	1.12	1.12	1.12	1.12	1.12	1.12	1.12	1.12	1.12	1.12	1.13	1.13	1.13	1.16	1.17
2	1	6	1	4	1.41	1.41	1.41	1.41	1.41	1.41	1.41	1.41	1.41	1.41	1.41	1.42	1.42	1.42	1.44	1.45
3	1	6	1	5	1.78	1.78	1.78	1.78	1.78	1.78	1.78	1.78	1.78	1.78	1.78	1.78	1.78	1.78	1.80	1.80
4	1	6	1	6	2.24	2.24	2.24	2.24	2.24	2.24	2.24	2.24	2.24	2.24	2.24	2.24	2.24	2.24	2.24	2.24
5	1	6	1	7	2.82	2.82	2.82	2.82	2.82	2.82	2.82	2.82	2.82	2.82	2.82	2.82	2.82	2.82	2.82	2.82
6	1	6	1	8	3.56	3.56	3.56	3.56	3.56	3.56	3.56	3.56	3.56	3.56	3.56	3.56	3.56	3.56	3.56	3.56
203,000	1	8	7	127,700	0.460	0.460	0.461	0.461	0.461	0.462	0.463	0.463	0.469	0.472	0.466	0.477	0.483	0.477	0.509	0.524
203,200	1	16	19	127,800	0.460	0.460	0.461	0.461	0.461	0.462	0.463	0.463	0.469	0.472	0.466	0.477	0.483	0.477	0.509	0.524
211,300	1	12	7	132,900	0.442	0.442	0.443	0.443	0.443	0.444	0.445	0.445	0.451	0.453	0.448	0.459	0.464	0.458	0.487	0.503
190,800	1	12	7	120,000	0.490	0.490	0.491	0.491	0.491	0.492	0.493	0.493	0.499	0.502	0.497	0.509	0.515	0.508	0.542	0.558
176,900	1	12	7	111,200	0.528	0.528	0.529	0.529	0.529	0.530	0.531	0.532	0.538	0.541	0.535	0.548	0.555	0.548	0.584	0.601
159,000	1	12	7	100,000	0.587	0.587	0.588	0.588	0.588	0.589	0.590	0.591	0.598	0.602	0.595	0.610	0.617	0.609	0.649	0.669
134,600	1	12	7	84,600	0.694	0.694	0.695	0.695	0.695	0.698	0.699	0.699	0.707	0.711	0.703	0.721	0.729	0.720	0.767	0.790
110,800	1	12	7	69,700	0.843	0.843	0.845	0.845	0.845	0.848	0.850	0.849	0.859	0.864	0.855	0.876	0.886	0.874	0.932	0.960
101,800	1	12	7	64,160	0.917	0.918	0.919	0.919	0.919	0.922	0.923	0.923	0.934	0.940	0.929	0.952	0.963	0.951	1.008	1.044
80,000	1	8	1	50,310	1.170	1.170	1.170	1.170	1.170	1.170	1.170	1.171	1.172	1.172	1.176	1.178	1.181	1.184	1.214	1.223

See notes following Table 55.

55. Direct-current Resistance for All-aluminum Wire

Size, A.w.g.	Size, cir. mils	Ohms per mile at 25°C. for 61 % conductivity	Size, A.w.g.	Size, cir. mils	Ohms per mile at 25°C. for 61 % conductivity
...	1,590,000	0.0587	...	500,000	0.187
...	1,510,000	0.0618	...	477,000	0.196
...	1,431,000	0.0652	...	397,500	0.235
...	1,351,500	0.0691	...	336,400	0.278
...	1,272,000	0.0734	...	300,000	0.311
...	1,192,500	0.0783	...	266,800	0.350
...	1,113,000	0.0839	4/0	211,600	0.441
...	1,033,500	0.0903	3/0	167,806	0.556
...	954,000	0.0979	2/0	133,077	0.702
...	874,500	0.107	1/0	105,535	0.885
...	795,000	0.117	1	83,693	1.12
...	750,000	0.124	2	66,371	1.41
...	715,500	0.131	3	52,635	1.78
...	636,000	0.147	4	41,741	2.24
...	556,500	0.168			

NOTES:

1. The d-c resistances are based on aluminum of 61 per cent conductivity. For stranded conductors, the resistances are 2 per cent greater than the equivalent solid conductor. This allows for increase of length due to an average length of lay as recommended by the American Institute of Electrical Engineers.

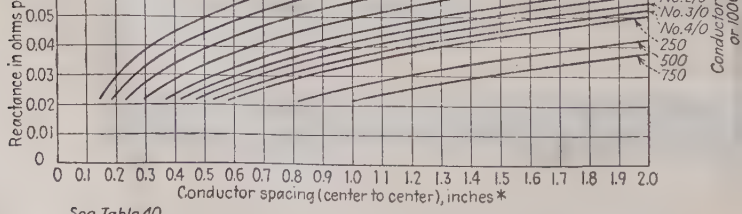
2. In computing the resistances of aluminum cable, steel-reinforced, no deduction is made for the conductance of the steel core.

3. The a-c resistances are based on calculations developed from actual tests.

4. No allowance has been made for increased length because of sag when the conductors are suspended.

56. Reactance of Single-conductor, Standard-strand, and Three-conductor Cables without Magnetic Binder (for Small Spacings)

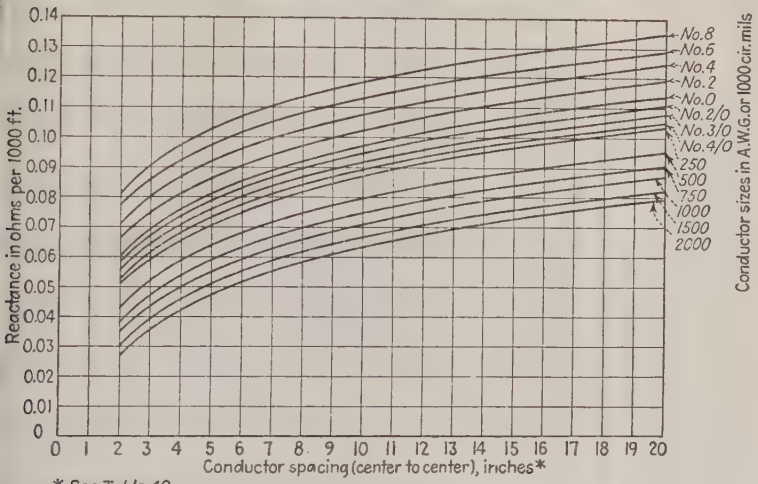
Ohms per 1,000 ft. to Neutral—at 60 cycles. (*General Electric Co.*)



See Table 40

57. Reactance of Single-conductor, Standard-strand, and Three-conductor Cables without Magnetic Binder (for Large Spacings)

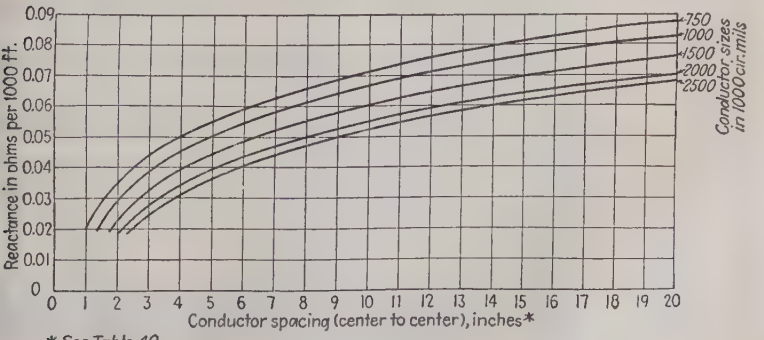
Ohms per 1,000 ft. to Neutral—at 60 cycles (*General Electric Co.*)



*See Table 40

58. Reactance of Single-conductor, Annular Cables

Ohms per 1,000 ft. to Neutral—at 60 cycles. (*General Electric Co.*)



*See Table 40

59. Twenty-five-cycle Reactance per Mile Stranded-copper Conductors Overhead Transmission Lines

(From Nesbit, "Electrical Characteristics of Transmission Circuits")

Size of conductor		Number of wires	Outside diameter in inches	25 cycle reactance x in ohms per mile of each conductor of a single-phase, two-phase or three-phase circuit. (See foot-notes)													
				Distance D between centers of conductors*													
Circular mils	American wire gauge (B. & S.)			2 inches (5.1 cm.)	4 inches (10.2 cm.)	6 inches (15.2 cm.)	8 inches (20.3 cm.)	10 inches (25.4 cm.)	12 inches (30.5 cm.)	15 inches (38.1 cm.)	18 inches (45.7 cm.)	21 inches (53.3 cm.)	24 inches (61.0 cm.)	27 inches (68.6 cm.)	30 inches (76.2 cm.)	33 inches (83.8 cm.)	36 inches (91.4 cm.)
2,000,000	....	127	1.631	.0582	.0932	.114	.128	.140	.149	.160	.169	.177	.184	.190	.195	.200	.204
1,900,000	....	127	1.590	.0595	.0945	.115	.130	.141	.150	.161	.171	.178	.185	.191	.196	.201	.206
1,800,000	....	127	1.548	.0609	.0959	.116	.131	.142	.151	.163	.172	.180	.186	.192	.198	.203	.207
1,700,000	....	127	1.504	.0623	.0973	.118	.132	.144	.153	.164	.173	.181	.188	.194	.199	.204	.208
1,600,000	....	127	1.459	.0638	.0989	.119	.134	.145	.154	.166	.175	.183	.189	.195	.201	.206	.210
1,500,000	....	91	1.412	.0656	.100	121	.136	.147	.156	.167	.177	.184	.191	.197	.202	.207	.212
1,400,000	....	91	1.364	.0673	.102	.123	.137	.149	.158	.169	.178	.186	.193	.199	.204	.209	.213
1,300,000	....	91	1.315	.0692	.104	.125	.139	.151	.160	.171	.180	.188	.195	.201	.206	.211	.215
1,200,000	....	91	1.263	.0712	.106	.127	.141	.153	.162	.173	.182	.190	.197	.203	.208	.213	.217
1,100,000	....	91	1.209	.0734	.108	.129	.144	.155	.164	.175	.185	.192	.199	.205	.210	.215	.220
1,000,000	....	61	1.152	.0760	.111	.132	.146	.157	.167	.178	.187	.195	.202	.208	.213	.218	.222
950,000	....	61	1.123	.0773	.112	.133	.147	.159	.168	.179	.188	.196	.203	.209	.214	.219	.223
900,000	....	61	1.093	.0787	.114	.134	.149	.160	.169	.181	.190	.198	.204	.210	.216	.220	.225
850,000	....	61	1.062	.0801	.115	.136	.150	.161	.171	.182	.191	.199	.206	.212	.217	.222	.226
800,000	....	61	1.031	.0816	.117	.137	.152	.163	.172	.184	.193	.201	.207	.213	.219	.223	.228
750,000	....	61	.998	.0833	.118	.139	.153	.165	.174	.185	.194	.202	.209	.215	.220	.225	.229
700,000	....	61	.964	.0850	.120	.141	.155	.166	.176	.187	.196	.204	.211	.217	.222	.227	.231
650,000	....	61	.929	.0869	.122	.142	.157	.168	.177	.189	.198	.206	.213	.218	.224	.229	.233
600,000	....	37	.891	.0393	.124	.145	.159	.171	.180	.191	.200	.208	.215	.221	.226	.231	.235
550,000	....	37	.853	.0915	.127	.147	.162	.173	.182	.193	.203	.210	.217	.223	.228	.233	.238
500,000	....	37	.814	.0939	.129	.149	.164	.175	.184	.196	.205	.213	.220	.225	.231	.236	.240
450,000	....	37	.772	.0965	.132	.152	.167	.178	.187	.198	.208	.215	.222	.228	.233	.238	.243
400,000	....	19	.725	.100	.135	.156	.170	.182	.191	.202	.211	.219	.226	.232	.237	.242	.246
350,000	....	19	.679	.104	.139	.159	.174	.185	.194	.206	.215	.223	.229	.235	.241	.245	.250

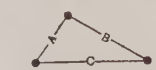
300,000	....	19	.628	.108	.143	.163	.178	.189	.198	.209	.219	.227	.233	.239	.245	.249	.254
250,000	....	19	.574	.112	.147	.168	.182	.194	.203	.214	.223	.231	.238	.244	.249	.254	.258
211,600	0000	7	.522	.119	.154	.175	.189	.201	.210	.221	.230	.238	.245	.251	.256	.261	.265
167,806	000	7	.464	.125	.160	.181	.195	.206	.216	.227	.236	.244	.251	.257	.262	.267	.271
133,077	00	7	.414	.131	.166	.186	.201	.212	.222	.233	.242	.250	.257	.263	.268	.273	.277
105,535	0	7	.368	.137	.172	.192	.207	.218	.227	.239	.248	.256	.262	.268	.274	.279	.283
83,693	1	7	.328	.143	.178	.198	.213	.224	.233	.245	.254	.262	.268	.274	.280	.284	.289
66,371	2	7	.292	.149	.184	.204	.219	.230	.239	.250	.260	.267	.274	.280	.285	.290	.295
52,635	3	7	.260	.154	.189	.210	.224	.236	.245	.256	.265	.273	.280	.286	.291	.296	.301
41,741	4	7	.232	.160	.195	.216	.230	.242	.251	.262	.271	.279	.286	.292	.297	.302	.306
33,102	5	7	.206	.166	.201	.222	.236	.247	.257	.268	.277	.285	.292	.298	.303	.308	.312
26,251	6	7	.184	.172	.207	.228	.242	.253	.263	.274	.283	.291	.298	.304	.309	.314	.318

The table values were derived from the equation $x = 2\pi fL$, in which x is the reactance in ohms; L is the inductance in henries per mile of single conductor and f is the frequency. The reactance at any other frequency than 25 cycles is $f/25$ times the table values.

The reactance x' at any spacing D' not given in the table is equal to the reactance x at the NEXT SMALLER spacing D given in the table plus the quantity $0.1164 \log_{10} D'/D$. Thus $x' = x + 0.1164 \log_{10} D'/D$. Or the reactance in ohms to be added to that at the next smaller spacing may be taken from table below

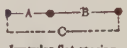
D'/D	1.05	1.10	1.15	1.20	1.25	1.30	1.35	1.40	1.45	1.50	1.55	1.60	1.65	.170	1.75	1.80	1.85	1.90	1.95	2.00
$x+$	.002	.005	.007	.009	.011	.013	.015	.017	.019	.020	.022	.024	.025	.027	.028	.030	.031	.032	.034	.035

* For any three-phase arrangement of conductors $D = \sqrt[3]{ABC}$. This resolves itself into $D = A$, B or C for symmetrical triangular spacing and into $D = 1.26\ A$ or B for regular flat spacing, it being immaterial whether the conductors are in a horizontal or vertical plane.

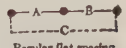


Unsymmetrical triangular spacing

Symmetrical triangular spacing



Irregular flat spacing



Regular flat spacing

Twenty-five-cycle Reactance per Mile Stranded-copper Conductors Overhead Transmission Lines (*Continued*)

Size of conductor		25 cycle reactance x in ohms per mile of each conductor of a single-phase, two-phase or three-phase circuit. (See foot-notes)																
		Distance D between centers of conductors*																
Circular mils	American wire gauge (B. & S.)	3.5 feet (1.07 m.)	4 feet (1.22 m.)	5 feet (1.52 m.)	6 feet (1.83 m.)	7 feet (2.13 m.)	8 feet (2.44 m.)	9 feet (2.74 m.)	11 feet (3.35 m.)	13 feet (3.96 m.)	15 feet (4.57 m.)	17 feet (5.18 m.)	19 feet (5.79 m.)	21 feet (6.40 m.)	23 feet (7.01 m.)	25 feet (7.62 m.)	30 feet (9.14 m.)	35 feet (10.67 m.)
2,000,000	....	.212	.219	.230	.239	.247	.254	.260	.270	.278	.286	.292	.298	.303	.307	.312	.321	.329
1,900,000	....	.213	.220	.231	.241	.248	.255	.261	.271	.280	.287	.293	.299	.304	.309	.313	.322	.330
1,800,000	....	.215	.222	.233	.242	.250	.257	.263	.273	.281	.288	.295	.300	.305	.310	.314	.323	.331
1,700,000	....	.216	.223	.234	.243	.251	.258	.264	.274	.283	.290	.296	.302	.307	.311	.316	.325	.333
1,600,000	....	.218	.225	.236	.245	.253	.260	.266	.276	.284	.291	.298	.303	.308	.313	.317	.326	.334
1,500,000	....	.219	.226	.238	.247	.255	.261	.267	.277	.286	.293	.299	.305	.310	.315	.319	.328	.336
1,400,000	....	.221	.228	.239	.248	.256	.263	.269	.279	.288	.295	.301	.307	.312	.316	.321	.330	.338
1,300,000	....	.223	.230	.241	.250	.258	.265	.271	.281	.289	.297	.303	.309	.314	.318	.323	.332	.340
1,200,000	....	.225	.232	.243	.252	.260	.267	.273	.283	.291	.299	.305	.311	.316	.320	.325	.334	.342
1,100,000	....	.227	.234	.245	.255	.262	.269	.275	.285	.294	.301	.307	.313	.318	.323	.327	.336	.344
1,000,000	....	.230	.237	.248	.257	.265	.272	.278	.288	.296	.304	.310	.315	.321	.325	.329	.339	.346
950,000	....	.231	.238	.249	.258	.266	.273	.279	.289	.298	.305	.311	.317	.322	.326	.331	.340	.348
900,000	....	.233	.239	.251	.260	.268	.274	.280	.290	.299	.306	.313	.318	.323	.328	.332	.341	.349
850,000	....	.234	.241	.252	.261	.269	.276	.282	.292	.300	.308	.314	.320	.325	.329	.333	.343	.350
800,000	....	.236	.242	.254	.263	.271	.277	.283	.293	.302	.309	.315	.321	.326	.331	.335	.344	.352
750,000	....	.237	.244	.255	.264	.272	.279	.285	.295	.304	.311	.317	.323	.328	.332	.337	.346	.354
700,000	....	.239	.246	.257	.266	.274	.281	.287	.297	.305	.313	.319	.324	.330	.334	.338	.348	.355
650,000	....	.241	.248	.259	.268	.276	.283	.289	.299	.307	.314	.321	.326	.331	.336	.340	.349	.357
600,000	....	.243	.250	.261	.270	.278	.285	.291	.301	.310	.317	.323	.329	.334	.338	.343	.352	.360
550,000	....	.245	.252	.263	.273	.280	.287	.293	.303	.312	.319	.325	.331	.336	.341	.345	.354	.362
500,000	....	.248	.255	.266	.275	.283	.290	.296	.306	.314	.321	.328	.333	.338	.343	.347	.356	.364
450,000	....	.250	.257	.269	.278	.286	.292	.298	.308	.317	.324	.330	.336	.341	.346	.350	.359	.367
400,000	....	.254	.261	.272	.282	.289	.296	.302	.312	.321	.328	.334	.340	.345	.349	.354	.363	.371
350,000	....	.258	.264	.276	.285	.293	.299	.305	.316	.324	.331	.338	.343	.348	.353	.357	.366	.374
300,000	....	.262	.268	.280	.289	.297	.303	.309	.319	.328	.335	.341	.347	.352	.357	.361	.370	.378

250,000	....	.266	.273	.284	.293	.301	.308	.314	.324	.333	.340	.346	.352	.357	.361	.366	.375	.383
211,600	0000	.273	.280	.291	.300	.308	.315	.321	.331	.340	.347	.353	.359	.364	.368	.373	.382	.390
167,806	000	.279	.286	.297	.306	.314	.321	.327	.337	.345	.353	.359	.365	.370	.374	.378	.388	.395
133,077	00	.285	.292	.303	.312	.320	.327	.333	.343	.351	.358	.365	.370	.375	.380	.384	.394	.401
105,535	0	.291	.297	.309	.318	.326	.333	.338	.349	.357	.364	.371	.376	.381	.386	.390	.399	.407
83,693	1	.297	.303	.315	.324	.332	.338	.344	.354	.363	.370	.377	.382	.387	.392	.396	.405	.413
66,371	2	.302	.309	.321	.330	.338	.344	.350	.360	.369	.376	.382	.388	.393	.398	.402	.411	.419
52,635	3	.308	.315	.326	.336	.343	.350	.356	.366	.375	.382	.388	.394	.399	.404	.408	.417	.425
41,741	4	.314	.321	.332	.341	.349	.356	.362	.372	.381	.388	.394	.400	.405	.409	.414	.423	.431
33,102	5	.320	.327	.338	.347	.355	.362	.368	.378	.386	.394	.400	.406	.411	.415	.419	429	.436
26,251	6	.326	.333	.344	.353	.361	.368	.374	.384	.392	.399	.406	.411	.417	.421	.425	.435	.442

The table values were derived from the equation $x = 2\pi fL$, in which x is the reactance in ohms; L is the inductance in henries per mile of single conducto. and f is the frequency. The reactance at any other frequency than 25 cycles is $f/25$ times the table values.

The reactance x' at any spacing D' not given in the table is equal to the reactance x at the NEXT SMALLER spacing D given in the table plus the quantity $0.1164 \log_{10} D'/D$. Thus $x' = x + 0.1164 \log_{10} D'/D$. Or the reactance in ohms to be added to that at the next smaller spacing may be taken from table below.

D'/D	1.05	1.10	1.15	1.20	1.25	1.30	1.35	1.40	1.45	1.50	1.55	1.60	1.65	1.70	1.75	1.80	1.85	1.90	1.95	2.00
$x+$	.002	.005	.007	.009	.011	.013	.015	.017	.019	.020	.022	.024	.025	.027	.028	.030	.031	.032	.034	.035

* For any three-phase arrangement of conductors $D = \sqrt[3]{ABC}$. This resolves itself into $D = A$, B or C for symmetrical triangular spacing and into $D = 1.26\ A$ or B for regular flat spacing, it being immaterial whether the conductors are in a horizontal or vertical plane.

Unsymmetrical triangular spacing — Symmetrical triangular spacing — Irregular flat spacing — Regular flat spacing

60. Sixty-cycle Reactance per Mile Stranded-copper Conductors Overhead Transmission Lines

(From Nesbit, "Electrical Characteristics of Transmission Circuits")

Size of conductor		60 cycle reactance x in ohms per mile of each conductor of a single-phase, two-phase or three-phase circuit. (See foot-notes)														
				Distance D between centers of conductors*												
Circular mils	American wire gauge (B. & S.)	Number of wires	Outside diameter in inches	2 inches (5.1 cm.)	4 inches (10.2 cm.)	6 inches (15.2 cm.)	8 inches (20.3 cm.)	10 inches (25.4 cm.)	12 inches (30.5 cm.)	15 inches (38.1 cm.)	18 inches (45.7 cm.)	21 inches (53.3 cm.)	24 inches (61.0 cm.)	27 inches (68.6 cm.)	30 inches (76.2 cm.)	33 inches (83.8 cm.)	36 inches (91.4 cm.)
2,000,000	....	127	1.631	.140	.224	.273	.308	.335	.357	.384	.406	.425	.441	.455	.468	.480	.490
1,900,000	....	127	1.590	.143	.227	.276	.311	.338	.360	.387	.409	.428	.444	.459	.471	.483	.494
1,800,000	....	127	1.548	.146	.230	.279	.314	.341	.363	.391	.413	.431	.448	.462	.475	.486	.497
1,700,000	....	127	1.504	.150	.234	.283	.318	.345	.367	.394	.416	.435	.451	.465	.478	.490	.500
1,600,000	....	127	1.459	.153	.237	.287	.321	.349	.371	.398	.420	.439	.455	.469	.482	.493	.504
1,500,000	....	91	1.412	.157	.241	.291	.326	.353	.375	.402	.424	.443	.459	.473	.486	.498	.508
1,400,000	....	91	1.364	.162	.246	.295	.330	.357	.379	.406	.428	.447	.463	.477	.490	.502	.512
1,300,000	....	91	1.315	.166	.250	.299	.334	.361	.383	.411	.433	.451	.468	.482	.495	.506	.517
1,200,000	....	91	1.263	.171	.255	.304	.339	.366	.388	.415	.438	.456	.472	.487	.500	.511	.522
1,100,000	....	91	1.209	.176	.260	.309	.344	.371	.394	.421	.443	.461	.478	.492	.505	.516	.527
1,000,000	....	61	1.152	.182	.267	.316	.351	.378	.400	.427	.449	.468	.484	.498	.511	.523	.533
950,000	....	61	1.123	.186	.270	.319	.354	.381	.403	.430	.452	.471	.487	.501	.514	.526	.536
900,000	....	61	1.093	.189	.273	.322	.357	.384	.406	.433	.455	.474	.490	.505	.517	.529	.540
850,000	....	61	1.062	.192	.276	.326	.360	.388	.410	.437	.459	.478	.494	.508	.521	.532	.543
800,000	....	61	1.031	.196	.280	.329	.364	.391	.413	.440	.463	.481	.497	.512	.525	.536	.547
750,000	....	61	.998	.200	.284	.333	.368	.395	.417	.444	.466	.485	.501	.516	.528	.540	.551
700,000	....	61	.964	.204	.288	.337	.372	.399	.421	.449	.471	.489	.506	.520	.533	.544	.555
650,000	....	61	.929	.209	.293	.342	.377	.404	.426	.453	.475	.494	.510	.524	.537	.549	.559
600,000	....	37	.891	.214	.298	.348	.382	.410	.432	.459	.481	.500	.516	.530	.543	.554	.565
550,000	....	37	.853	.220	.304	.353	.388	.415	.437	.464	.486	.505	.521	.535	.548	.560	.570
500,000	....	37	.814	.225	.309	.359	.394	.421	.443	.470	.492	.511	.527	.541	.554	.565	.576
450,000	....	37	.772	.232	.316	.365	.400	.427	.449	.476	.498	.517	.533	.548	.560	.572	.582
400,000	....	19	.725	.241	.325	.374	.409	.436	.458	.485	.507	.526	.542	.557	.569	.581	.592
350,000	....	19	.679	.249	.333	.382	.417	.444	.466	.493	.516	.534	.550	.565	.578	.589	.600
300,000	....	19	.628	.258	.342	.392	.426	.454	.476	.503	.525	.544	.560	.574	.587	.598	.608

250,000	....	19	.574	.269	.353	.403	.438	.465	.487	.514	.536	.555	.571	.585	.598	.610	.620
211,600	0000	7	.522	.286	.370	.419	.454	.481	.504	531	.553	.571	.588	.302	.615	.626	.637
167,806	000	7	.464	.300	.384	.434	.468	.495	.518	.545	.567	.586	.602	.616	.629	.640	.651
133,077	00	7	.414	.314	.398	.448	.482	.510	.532	.559	.581	.600	.616	.630	.643	.654	.665
105,535	0	7	.368	.328	.412	.462	.497	.524	.546	.573	.595	.614	.630	.644	.657	.668	.679
83,693	1	7	.328	.342	.427	.476	.511	.538	.560	.587	.609	.628	.644	.658	.671	.683	.693
66,371	2	7	.292	.356	.441	.490	.525	.552	.574	.601	.623	.642	.658	.672	.685	.697	.707
52,635	3	7	.260	.371	.455	.504	.539	.566	.588	.615	.637	.656	.672	.686	.699	.711	.721
41,741	4	7	.232	.385	.469	.518	.553	.580	.602	.629	.651	.670	.686	.700	.713	.725	.735
33,102	5	7	.206	.399	.483	.532	.567	.594	.616	.643	.665	.684	.700	.714	.727	.739	.749
26,251	6	7	.184	.413	.497	.546	.581	.608	.630	.657	.679	.698	.714	.729	.741	.753	.763

The table values were derived from the equation $x = 2\pi fL$, in which x is the reactance in ohms, L is the inductance in henries per mile of single conductor and is the frequency. The reactance at any other frequency than 60 cycles is $f/60$ times the table values.

The reactance x at any spacing D' not given in the table is equal to the reactance x at the NEXT SMALLER spacing D given in the table plus the quantity $0.2794 \log_{10} D'/D$. Thus $x' = x + 0.2794 \log_{10} D'/D$. Or the reactance in ohms to be added to that at the next smaller spacing may be taken from table below.

D′/D	1.05	1.10	1.15	1.20	1.25	1.30	1.35	1.40	1.45	1.50	1.55	1.60	1.65	1.70	1.75	1.80	1.85	1.90	1.95	2.00
$x+$	.006	.012	.017	.022	.027	.032	.036	.041	.045	.049	.053	.057	.061	.064	.068	.071	.075	.078	.081	.084

*For any three-phase arrangement of conductors $D = \sqrt[3]{ABC}$. This resolves itself into $D = A$, B or C for symmetrical triangular spacing and into $D = 1.26\ A$ or B for regular flat spacing, it being immaterial whether the conductors are in a horizontal or vertical plane.

Sixty-cycle Reactance per Mile Stranded-copper Conductors Overhead Transmission Lines (*Continued*)

Size of conductor		60 cycle reactance x in ohms per mile of each conductor of a single-phase, two-phase or three-phase circuit. (See foot-notes)																
		Distance D between centers of conductors*																
Circular mils	American wire gauge (B. & S.)	3.5 feet (1.07 m.)	4 feet (1.22 m.)	5 feet (1.52 m.)	6 feet (1.83 m.)	7 feet (2.13 m.)	8 feet (2.44 m.)	9 feet (2.74 m.)	11 feet (3.35 m.)	13 feet (3.96 m.)	15 feet (4.57 m.)	17 feet (5.16 m.)	18 feet (5.79 m.)	21 feet (6.40 m.)	23 feet (7.01 m.)	25 feet (7.62 m.)	30 feet (9.14 m.)	35 feet (10.67 m.)
2,000,000	....	.509	.525	.552	.574	.593	.609	.624	.648	.668	.686	.701	.714	.727	.738	.748	.770	.788
1,900,000	....	.512	.528	.555	.578	.596	.613	.627	.651	.671	.689	.704	.717	.730	.741	.751	.773	.792
1,800,000	....	.515	.532	.559	.581	.600	.616	.630	.654	.675	.692	.707	.721	.733	.744	.754	.776	.795
1,700,000	....	.519	.535	.562	.584	.603	.619	.634	.658	.678	.696	.711	.724	.736	.747	.758	.780	.798
1,600,000	....	.523	.539	.566	.588	.607	.623	.637	.662	.682	.699	.714	.728	.740	.751	.761	.783	.802
1,500,000	....	.527	.543	.570	.592	.611	.627	.641	.666	.686	.703	.719	.732	.744	.755	.765	.787	.806
1,400,000	....	.531	.547	.574	.596	.615	.631	.646	.670	.690	.708	.723	.736	.748	.759	.770	.792	.810
1,300,000	....	.535	.552	.579	.601	.620	.636	.650	.674	.695	.712	.727	.741	.753	.764	.774	.796	.815
1,200,000	....	.540	.557	.584	.606	.624	.641	.655	.679	.700	.717	.732	.746	.758	.769	.779	.801	.820
1,100,000	....	.546	.502	.589	.611	.630	.646	.660	.685	.705	.722	.737	.751	.763	.774	.784	.806	.825
1,000,000	....	.552	.568	.595	.617	.636	.652	.666	.691	.711	.728	.744	.757	.769	.780	.790	.813	.831
950,000	....	.555	.571	.598	.620	.639	.655	.670	.694	.714	.732	.747	.760	.772	.783	.794	.816	.834
900,000	....	.558	.574	.601	.624	.642	.659	.673	.697	.717	.735	.750	.763	.776	.787	.797	.819	.838
850,000	....	.562	.578	.605	.627	.646	.662	.676	.701	.721	.738	.753	.767	.779	.790	.800	.822	.841
800,000	....	.565	.582	.609	.631	.649	.666	.680	.704	.725	.742	.757	.771	.783	.794	.804	.826	.845
750,000	....	.569	.585	.613	.635	.653	.670	.684	.708	.729	.746	.761	.775	.787	.798	.808	.830	.849
700,000	....	.573	.590	.617	.639	.658	.674	.688	.712	.733	.750	.765	.779	.791	.802	.812	.834	.853
650,000	....	.578	.594	.621	.643	.662	.678	.693	.717	.737	.755	.770	.783	.795	.806	.817	.839	.857
600,000	....	.584	.600	.627	.649	.668	.684	.698	.723	.743	.760	.775	.789	.801	.812	.822	.844	.863
550,000	....	.589	.605	.632	.654	.673	.689	.704	.728	.748	.766	.781	.794	.806	.817	.828	.850	.868
500,000	....	.595	.611	.638	.660	.679	.695	.709	.734	.754	.771	.786	.800	.812	.823	.833	.855	.874
450,000	....	.601	.617	.644	.667	.685	.701	.716	.740	.760	.778	.793	.806	.819	.830	.840	.862	.881
400,000	....	.610	.626	.654	.676	.694	.711	.725	.749	.769	.787	.802	.816	.828	.839	.849	.871	.890
350,000	....	.618	.635	.662	.684	.702	.719	.733	.757	.778	.795	.810	.824	.836	.847	.857	.879	.898
300,000	....	.628	.644	.671	.693	.712	.728	.742	.767	.787	.804	.819	.833	.845	.856	.866	.888	.907
250,000	....	.639	.655	.682	.704	.723	.739	.753	.778	.798	.815	.831	.844	.856	.867	.877	.899	.918

211,600	0000	.656	.672	.699	.721	.740	.756	.770	.795	.815	.832	.847	.861	.873	.884	.894	.916	.935
167,806	000	.670	.686	.713	.735	.754	.770	.784	.809	.829	.846	.861	.875	.887	.898	.908	.930	.949
133,077	00	.684	.700	.727	.749	.768	.784	.798	.823	.843	.860	.875	.889	.901	.912	.922	.944	.963
105,535	0	.698	.714	.741	.763	.782	.798	.812	.837	.857	.874	.890	.903	.915	.926	.936	.958	.977
83,693	1	.712	.728	.755	.777	.796	.812	.826	.851	.871	.888	.904	.917	.929	.940	.950	.973	.991
66,371	2	.726	.742	.769	.791	.810	.826	.841	.865	.885	.902	.918	.931	.943	.954	.964	.987	1.005
52,635	3	.740	.756	.783	.805	.824	.840	.855	.879	.899	.917	.932	.945	.957	.968	.979	1.001	1.019
41,741	4	.754	.770	.797	.819	.838	.854	.869	.893	.913	.931	.946	.959	.971	.982	.993	1.015	1.033
33,102	5	.768	.784	.811	.833	.852	.868	.883	.907	.927	.945	.960	.973	.986	.997	1.007	1.029	1.048
26,251	6	.782	.798	.825	.848	.866	.882	.897	.921	.941	.959	.974	.987	1.000	1.011	1.021	1.043	1.062

The table values were derived from the equation $x = 2\pi fL$, in which x is the reactance in ohms, L is the inductanec in henries per mile of single conductor and f is the frequency. The reactance at any other frequency than 60 cycles is $f/60$ times the table values.

The reactance x at any spacing D' not given in the table is equal to the reactance x at the NEXT SMALLER spacing D given in the table plus the quantity $0.2794 \log_{10} D'/D$. Thus $x' = x + 0.2794 \log_{10} D'/D$. Or the reactance in ohms to be added to that at the next smaller spacing may be taken from table below.

D'/D	1.05	1.10	1.15	1.20	1.25	1.30	1.35	1.40	1.45	1.50	1.55	1.60	1.65	1.70	1.75	1.80	1.85	1.90	1.95	2.00
$x+$	.006	.012	.017	.022	.027	.032	.036	.041	.045	.049	.053	.057	.061	.064	.068	.071	.075	.078	.081	.084

*For any three-phase arrangement of conductors $D = \sqrt[3]{ABC}$. This resolves itself into $D = A$, B or C for symmetrical triangular spacing and into $D = 1.26\,A$ or B for regular flat spacing, it being immaterial whether the conductors are in a horizontal or vertical plane.

Unsymmetrical triangular spacing. Symmetrical triangular spacing. Irregular flat spacing. Regular flat spacing.

61. Average 60-cycle Reactance of All-steel Amerductors, in Ohms per 1,000 ft. of Conductor at 68°F.

Size, B.w.g.	Spacing[a] between conductors, in.	Reactance,[a] ohms per 1,000 ft., for various loadings									
		Three-wire strand, Type S-3					Solid wire, Type S				
		1 amp.	5 amp.	10 amp.	15 amp.	20 amp.	1 amp.	5 amp.	10 amp.	15 amp.	20 amp.
4	12	0.22	0.24	0.28	0.31	0.35	0.35	0.50	0.69	0.84	1.07
	24	0.24	0.26	0.29	0.33	0.37	0.37	0.52	0.71	0.86	1.09
	36	0.25	0.26	0.30	0.34	0.38	0.38	0.53	0.72	0.87	1.10
	48	0.25	0.27	0.31	0.35	0.39	0.38	0.53	0.72	0.88	1.10
	60	0.26	0.28	0.32	0.36	0.39	0.39	0.54	0.73	0.88	1.11
	120	0.27	0.29	0.33	0.37	0.41	0.40	0.56	0.75	0.90	1.13
6	12	0.24	0.28	0.32	0.36	....	0.45	0.62	0.83	1.06	
	24	0.26	0.30	0.34	0.37	....	0.46	0.64	0.84	1.07	
	36	0.27	0.31	0.34	0.38	....	0.47	0.65	0.85	1.08	
	48	0.27	0.31	0.35	0.39	....	0.48	0.65	0.86	1.09	
	60	0.28	0.32	0.36	0.39	....	0.49	0.66	0.86	1.09	
	120	0.30	0.33	0.37	0.41	....	0.50	0.67	0.88	1.11	
8	12	0.27	0.30	0.34	....	....	0.47	0.70	0.97		
	24	0.28	0.32	0.36	....	....	0.49	0.72	0.98		
	36	0.29	0.33	0.37	....	....	0.50	0.73	0.99		
	48	0.30	0.33	0.37	....	....	0.51	0.74	1.00		
	60	0.31	0.34	0.38	....	....	0.51	0.74	1.01		
	120	0.32	0.36	0.39	....	....	0.53	0.76	1.02		

[a] See Table 40.

62. Average 60-cycle Reactance of Steel-copper Amerductors in Ohms per 1,000 Ft. of Conductor at 68°F.

Size, A.w.g.	Reactance,[a] ohms per 1000 ft., for various spacings between conductors					
	12 in.	24 in.	36 in.	48 in.	60 in.	120 in.
2	0.13	0.15	0.16	0.17	0.17	0.19
4	0.13	0.14	0.15	0.16	0.16	0.18
6	0.13	0.14	0.15	0.16	0.16	0.18
8	0.13	0.14	0.15	0.16	0.17	0.18
10	0.15	0.17	0.17	0.18	0.19	0.20
12	0.17	0.18	0.19	0.20	0.20	0.22

[a] See Table 40.

63. 60-cycle Reactances of Copperweld-copper and Copperweld Conductors, in Ohms per 1,000 Ft. of Each Conductor

Conductor	Distance between centers of conductors[a]								
	12 in.	24 in.	36 in.	48 in.	60 in.	72 in.	84 in.	96 in.	108 in.
Composite Cables Copperweld—Copper Conductors									
2A	0.121	0.137	0.146	0.153	0.158	0.162	0.166	0.169	0.172
3A	0.124	0.140	0.149	0.156	0.161	0.165	0.169	0.172	0.175
4A	0.127	0.143	0.152	0.159	0.164	0.168	0.172	0.175	0.178
5A	0.129	0.145	0.154	0.161	0.166	0.170	0.174	0.177	0.180
6A	0.132	0.148	0.157	0.164	0.169	0.173	0.177	0.180	0.183
7A	0.135	0.151	0.160	0.167	0.172	0.176	0.180	0.183	0.186
8A	0.138	0.154	0.163	0.170	0.175	0.179	0.183	0.186	0.189
8C	0.138	0.154	0.163	0.170	0.175	0.179	0.183	0.186	0.188
8D	0.138	0.154	0.164	0.170	0.175	0.180	0.183	0.186	0.189
9½D	0.144	0.160	0.169	0.175	0.181	0.185	0.188	0.191	0.194
Copperweld Conductors—3-wire Strands									
3 No. 8 A.w.g.	0.137	0.153	0.162	0.169	0.174	0.178	0.182	0.185	0.188
3 No. 9 A.w.g.	0.139	0.155	0.164	0.171	0.176	0.180	0.184	0.187	0.190
3 No. 10 A.w.g.	0.142	0.158	0.167	0.174	0.179	0.183	0.187	0.190	0.193
3 No. 11 A.w.g.	0.145	0.161	0.170	0.177	0.182	0.186	0.190	0.193	0.196
3 No. 12 A.w.g.	0.147	0.163	0.172	0.179	0.184	0.188	0.192	0.195	0.198
Copperweld Conductors—Solid Wires									
No. 6 A.w.g.	0.144	0.160	0.169	0.176	0.181	0.185	0.189	0.192	0.195
No. 7 A.w.g.	0.146	0.162	0.171	0.178	0.183	0.187	0.191	0.194	0.197
No. 8 A.w.g.	0.149	0.165	0.174	0.181	0.186	0.190	0.194	0.197	0.200

NOTE.—For description of composite cables refer to Div. 2.
[a] See Table 40.

60-cycle reactances for other spacing may be determined from the ollowing formula:

$$X_d = X_{12} + 0.05293 \log_{10}\left(\frac{d}{12}\right)$$

here X_d = 60-cycle reactance in ohms per 1,000 ft. for a spacing of d nches; X_{12} = 60-cycle reactance in ohms per 1,000 ft. for a spacing of 2 in.; and d = spacing between centers of conductors, in inches.

64. 25-cycle Reactance[a] per Mile of Single-conductor Aluminum Cable, Steel-reinforced

Cir. mils or A.w.g. (B. & S.) Alum.	No. of wires		Distance d between centers of conductors[c]																
	Alum.	Steel	2 ft.	2.5 ft.	3 ft.	3.5 ft.	4 ft.	5 ft.	6 ft.	7 ft.	8 ft.	9 ft.	11 ft.	13 ft.	15 ft.	17 ft.	19 ft.	21 ft.	23 ft.	25 ft.
			25- cycle reactance x in ohms per mile of each conductor of a single-phase, two-phase, or three-phase circuit																
			Multiple-layer Conductors[b]—All Current Densities																
1,590,000	54	19	0.185	0.196	0.205	0.213	0.220	0.231	0.240	0.248	0.255	0.261	0.271	0.279	0.286	0.292	0.298	0.303	0.308	0.312
1,510,500	54	19	0.186	0.197	0.206	0.214	0.221	0.232	0.241	0.249	0.256	0.262	0.272	0.281	0.288	0.294	0.300	0.305	0.309	0.314
1,431,000	54	19	0.187	0.198	0.208	0.216	0.222	0.234	0.243	0.251	0.257	0.263	0.274	0.282	0.289	0.296	0.301	0.306	0.311	0.315
1,351,500	54	19	0.189	0.200	0.209	0.217	0.224	0.235	0.244	0.252	0.259	0.265	0.275	0.283	0.291	0.297	0.303	0.308	0.312	0.316
1,272,000	54	19	0.190	0.202	0.211	0.219	0.225	0.237	0.246	0.254	0.260	0.266	0.276	0.285	0.292	0.298	0.304	0.309	0.314	0.318
1,192,500	54	19	0.192	0.203	0.212	0.220	0.227	0.238	0.247	0.255	0.262	0.268	0.278	0.287	0.294	0.300	0.306	0.311	0.315	0.320
1,113,000	54	19	0.194	0.205	0.214	0.222	0.229	0.240	0.249	0.257	0.264	0.270	0.280	0.288	0.296	0.302	0.307	0.312	0.317	0.321
1,033,500	54	7	0.195	0.207	0.216	0.224	0.230	0.242	0.251	0.259	0.265	0.271	0.282	0.290	0.297	0.304	0.309	0.314	0.319	0.323
954,000	54	7	0.198	0.209	0.218	0.226	0.233	0.244	0.253	0.261	0.268	0.274	0.284	0.292	0.299	0.306	0.311	0.316	0.321	0.325
900,000	54	7	0.199	0.210	0.219	0.227	0.234	0.245	0.255	0.262	0.269	0.275	0.285	0.294	0.301	0.307	0.313	0.318	0.323	0.327
874,000	54	7	0.200	0.211	0.220	0.228	0.235	0.246	0.256	0.263	0.270	0.276	0.286	0.295	0.302	0.308	0.314	0.319	0.324	0.328
795,000	54	7	0.202	0.213	0.223	0.230	0.237	0.248	0.258	0.265	0.272	0.278	0.288	0.297	0.304	0.310	0.316	0.321	0.326	0.330
795,000	26	7	0.201	0.212	0.222	0.229	0.236	0.247	0.257	0.264	0.271	0.277	0.287	0.296	0.303	0.309	0.315	0.320	0.324	0.329
795,000	30	19	0.199	0.210	0.219	0.227	0.234	0.245	0.255	0.262	0.269	0.275	0.285	0.293	0.301	0.307	0.313	0.318	0.322	0.326
715,500	54	7	0.205	0.216	0.225	0.233	0.240	0.251	0.260	0.268	0.275	0.281	0.291	0.299	0.307	0.313	0.319	0.324	0.328	0.332
715,500	26	7	0.204	0.215	0.224	0.232	0.239	0.250	0.259	0.267	0.274	0.280	0.290	0.298	0.306	0.312	0.317	0.323	0.327	0.331
715,500	30	19	0.201	0.212	0.222	0.230	0.237	0.248	0.257	0.265	0.272	0.278	0.288	0.296	0.304	0.310	0.315	0.320	0.325	0.329
666,600	54	7	0.207	0.218	0.227	0.235	0.242	0.253	0.262	0.270	0.277	0.283	0.293	0.301	0.308	0.315	0.320	0.325	0.330	0.334
636,000	54	7	0.208	0.219	0.228	0.236	0.243	0.254	0.263	0.271	0.278	0.284	0.294	0.302	0.310	0.316	0.322	0.327	0.331	0.335
636,000	26	7	0.207	0.218	0.227	0.235	0.242	0.253	0.262	0.270	0.277	0.283	0.293	0.301	0.309	0.315	0.320	0.326	0.330	0.334
636,000	30	19	0.205	0.216	0.225	0.233	0.240	0.251	0.260	0.268	0.275	0.281	0.291	0.299	0.306	0.313	0.318	0.323	0.328	0.332
605,000	54	7	0.209	0.220	0.230	0.237	0.244	0.255	0.265	0.272	0.279	0.285	0.295	0.304	0.311	0.317	0.323	0.328	0.332	0.337
605,000	26	7	0.208	0.219	0.228	0.236	0.243	0.254	0.264	0.271	0.278	0.284	0.294	0.303	0.310	0.316	0.322	0.327	0.331	0.336
556,500	26	7	0.210	0.221	0.230	0.238	0.245	0.256	0.266	0.273	0.280	0.286	0.296	0.305	0.312	0.318	0.324	0.329	0.334	0.338
556,500	30	7	0.208	0.219	0.228	0.236	0.243	0.254	0.263	0.271	0.278	0.284	0.294	0.302	0.310	0.316	0.322	0.327	0.331	0.336

500,000	30	7	0.210	0.222	0.231	0.239	0.245	0.257	0.266	0.274	0.280	0.286	0.297	0.305	0.312	0.319	0.324	0.329	0.334	0.338
477,000	26	7	0.214	0.225	0.235	0.242	0.249	0.260	0.270	0.277	0.284	0.290	0.300	0.309	0.316	0.322	0.328	0.333	0.337	0.342
477,000	30	7	0.212	0.223	0.232	0.240	0.247	0.258	0.267	0.275	0.282	0.288	0.298	0.306	0.316	0.320	0.325	0.331	0.335	0.339
397,500	26	7	0.219	0.230	0.239	0.247	0.254	0.265	0.274	0.282	0.289	0.295	0.305	0.313	0.320	0.325	0.332	0.337	0.342	0.346
397,500	30	7	0.216	0.227	0.237	0.244	0.251	0.263	0.272	0.279	0.286	0.292	0.302	0.311	0.318	0.324	0.330	0.335	0.340	0.344
336,400	26	7	0.223	0.234	0.243	0.251	0.258	0.269	0.278	0.286	0.293	0.299	0.309	0.317	0.325	0.331	0.337	0.342	0.346	0.350
336,400	30	7	0.220	0.232	0.241	0.249	0.256	0.267	0.276	0.284	0.291	0.297	0.307	0.315	0.322	0.329	0.334	0.339	0.344	0.348
300,000	26	7	0.226	0.237	0.246	0.254	0.261	0.272	0.281	0.289	0.296	0.302	0.312	0.320	0.328	0.334	0.340	0.345	0.349	0.353
300,000	30	7	0.223	0.235	0.244	0.252	0.258	0.270	0.279	0.287	0.293	0.299	0.310	0.318	0.325	0.332	0.337	0.342	0.347	0.351
266,800	26	7	0.229	0.240	0.249	0.257	0.264	0.275	0.284	0.292	0.299	0.305	0.315	0.323	0.330	0.337	0.342	0.348	0.352	0.356

Single-layer Conductors[d]—Current Density 0 Amp. per Sq. In.

266,800	6	7	0.229	0.241	0.250	0.258	0.264	0.276	0.285	0.293	0.299	0.305	0.316	0.324	0.331	0.338	0.343	0.348	0.353	0.357
4/0	6	1	0.253	0.265	0.274	0.282	0.288	0.300	0.309	0.317	0.323	0.329	0.339	0.348	0.355	0.362	0.367	0.372	0.377	0.381
3/0	6	1	0.260	0.271	0.281	0.288	0.295	0.306	0.316	0.323	0.330	0.336	0.346	0.355	0.362	0.368	0.374	0.379	0.384	0.388
2/0	6	1	0.266	0.277	0.287	0.294	0.301	0.312	0.322	0.329	0.336	0.342	0.352	0.361	0.368	0.374	0.380	0.385	0.390	0.394
1/0	6	1	0.272	0.283	0.292	0.300	0.307	0.318	0.327	0.335	0.342	0.348	0.358	0.366	0.374	0.380	0.386	0.391	0.395	0.399
1	6	1	0.277	0.288	0.297	0.305	0.312	0.323	0.332	0.340	0.347	0.353	0.363	0.372	0.379	0.385	0.391	0.396	0.400	0.405
2	6	1	0.282	0.293	0.302	0.310	0.317	0.328	0.338	0.345	0.352	0.358	0.368	0.377	0.384	0.390	0.396	0.401	0.405	0.410
3	6	1	0.287	0.298	0.307	0.315	0.322	0.333	0.343	0.350	0.357	0.363	0.373	0.382	0.389	0.395	0.401	0.406	0.410	0.415
4	6	1	0.292	0.304	0.313	0.321	0.327	0.339	0.348	0.356	0.362	0.368	0.379	0.387	0.394	0.400	0.406	0.411	0.416	0.420
5	6	1	0.297	0.309	0.318	0.326	0.332	0.344	0.353	0.361	0.368	0.373	0.384	0.392	0.399	0.406	0.411	0.416	0.421	0.425
6	6	1	0.303	0.314	0.324	0 331	0.338	0.349	0.359	0.366	0.373	0.379	0.389	0.398	0.405	0.411	0.417	0.422	0.427	0.431
203,000	8	7	0.237	0.248	0.257	0.265	0.272	0.283	0.292	0.300	0.307	0.313	0.323	0.331	0.338	0.345	0.350	0.356	0.360	0.364
203,200	16	19	0.226	0.238	0.247	0.255	0.262	0.273	0.282	0.290	0.297	0.302	0.313	0.321	0.328	0.335	0.340	0.345	0.350	0.354
211,300	12	7	0.230	0.241	0.251	0.258	0.265	0.276	0.286	0.293	0.300	0.306	0.316	0.325	0.332	0.338	0.344	0.349	0.353	0.358
190,800	12	7	0.233	0.244	0.253	0.261	0.277	0.279	0.288	0.296	0.303	0.309	0.319	0.327	0.335	0.341	0.347	0.352	0.356	0.360
176,900	12	7	0.235	0.246	0.255	0.263	0.270	0.281	0.290	0.298	0.305	0.311	0.321	0.329	0.337	0.343	0.348	0.353	0.358	0.362

[a] The table values were derived from the equation $x = 2\pi fL$, in which x = the reactance in ohms; L = the inductance in henries per mile of single conductor, and f = the frequency. The reactance at any other frequency than 25 cycles is $f/25$ times the table values. The reactance x' at any spacing D' not given in the table is equal to the reactance x at the next smaller spacing D given in the table plus the quantity $0.1164 \log_{10} D'/D$. Thus $x' = x + 0.1164 \log_{10} D'/D$. Or the reactance in ohms, to be added to that at the next smaller spacing may be taken from table below:

D'/D	1.05	1.10	1.15	1.20	1.25	1.30	1.35	1.40	1.45	1.50	1.55	1.60	1.65	1.70	1.75	1.80	1.85	1.90	1.95	2.00
$x +$	0.002	0.005	0.007	0.009	0.011	0.013	0.015	0.017	0.019	0.020	0.022	0.024	0.025	0.027	0.028	0.030	0.031	0.032	0.034	0.035

[b] By multiple-layer conductors is meant conductors with two or more layers of aluminum over the steel core.
[c] See Table 40.
[d] By single-layer conductors is meant conductors with one layer of aluminum over the steel core.

25-cycle Reactance[a] per Mile of Single-conductor Aluminum Cable, Steel-reinforced (*Continued*)

Cir. mils or A.w.g. (B. & S.) Alum.	No. of wires		Distance d between centers of conductors[c]																
	Alum.	Steel	2 ft.	2.5 ft.	3 ft.	3.5 ft.	4 ft.	5 ft.	6 ft.	7 ft.	8 ft.	9 ft.	11 ft.	13 ft.	15 ft.	17 ft.	19 ft.	21 ft.	23 ft.	25 ft.
			25-cycle reactance x in ohms per mile of each conductor of a single-phase, two-phase, or three-phase circuit																
Single-layer Conductors[d]—Current Density 0 Amp. per Sq. In. (*Continued*)																			
159,000	12	7	0.237	0.249	0.258	0.266	0.272	0.284	0.293	0.301	0.307	0.313	0.323	0.332	0.339	0.345	0.351	0.356	0.361	0.365
134,600	12	7	0.241	0.253	0.262	0.270	0.276	0.288	0.297	0.305	0.312	0.317	0.328	0.336	0.343	0.350	0.355	0.360	0.365	0.369
110,800	12	7	0.246	0.258	0.267	0.275	0.282	0.293	0.302	0.310	0.317	0.323	0.333	0.341	0.348	0.355	0.360	0.365	0.370	0.374
101,800	12	7	0.249	0.260	0.269	0.277	0.284	0.295	0.304	0.312	0.319	0.325	0.335	0.343	0.350	0.357	0.362	0.367	0.372	0.376
80,000	8	1	0.276	0.288	0.297	0.305	0.311	0.323	0.332	0.339	0.346	0.352	0.362	0.371	0.378	0.384	0.390	0.395	0.400	0.404
Single-layer Conductors[d]—Current Density 600 Amp. per Sq. In.																				
266,800	6	7	0.237	0.248	0.257	0.265	0.272	0.283	0.292	0.300	0.307	0.313	0.323	0.332	0.339	0.345	0.351	0.356	0.360	0.365
4/0	6	1	0.262	0.273	0.282	0.290	0.297	0.308	0.317	0.325	0.332	0.338	0.348	0.356	0.364	0.370	0.376	0.381	0.385	0.389
3/0	6	1	0.266	0.277	0.286	0.294	0.301	0.312	0.321	0.329	0.336	0.342	0.352	0.361	0.368	0.374	0.380	0.385	0.389	0.394
2/0	6	1	0.270	0.282	0.291	0.299	0.305	0.317	0.326	0.334	0.340	0.346	0.357	0.365	0.372	0.379	0.384	0.389	0.394	0.398
0	6	1	0.275	0.286	0.295	0.303	0.310	0.321	0.330	0.338	0.345	0.351	0.361	0.369	0.377	0.383	0.389	0.394	0.398	0.402
1	6	1	0.279	0.291	0.300	0.308	0.314	0.326	0.335	0.343	0.349	0.355	0.366	0.374	0.381	0.388	0.393	0.398	0.403	0.407
2	6	1	0.284	0.295	0.304	0.312	0.319	0.330	0.339	0.347	0.354	0.360	0.370	0.379	0.386	0.392	0.398	0.403	0.407	0.411
3	6	1	0.288	0.299	0.309	0.316	0.323	0.335	0.344	0.351	0.358	0.364	0.374	0.383	0.390	0.396	0.402	0.407	0.412	0.416
4	6	1	0.293	0.304	0.313	0.321	0.328	0.339	0.348	0.356	0.363	0.369	0.379	0.387	0.395	0.401	0.407	0.412	0.416	0.420
5	6	1	0.298	0.310	0.319	0.327	0.333	0.345	0.354	0.362	0.368	0.374	0.384	0.393	0.400	0.406	0.412	0.417	0.422	0.426
6	6	1	0.304	0.316	0.325	0.332	0.339	0.351	0.360	0.368	0.374	0.380	0.390	0.399	0.406	0.412	0.418	0.423	0.428	0.432
203,000	8	7	0.243	0.253	0.262	0.270	0.277	0.288	0.297	0.305	0.312	0.318	0.328	0.337	0.344	0.350	0.355	0.361	0.366	0.370
203,200	16	19	0.232	0.243	0.252	0.260	0.267	0.278	0.287	0.295	0.302	0.308	0.318	0.326	0.334	0.340	0.346	0.351	0.355	0.360
211,300	12	7	0.235	0.247	0.256	0.264	0.271	0.282	0.291	0.299	0.306	0.312	0.322	0.330	0.337	0.344	0.349	0.354	0.359	0.363
190,800	12	7	0.238	0.249	0.259	0.266	0.273	0.284	0.294	0.301	0.308	0.314	0.324	0.333	0.340	0.346	0.352	0.357	0.361	0.366
176,900	12	7	0.240	0.251	0.260	0.268	0.275	0.286	0.296	0.303	0.310	0.316	0.326	0.335	0.342	0.348	0.354	0.360	0.364	0.368
159,000	12	7	0.243	0.254	0.263	0.271	0.278	0.289	0.298	0.306	0.313	0.319	0.329	0.337	0.344	0.351	0.356	0.361	0.366	0.370
134,600	12	7	0.247	0.258	0.267	0.275	0.282	0.293	0.302	0.310	0.317	0.323	0.330	0.342	0.349	0.355	0.361	0.366	0.370	0.375
110,800	12	7	0.252	0.263	0.272	0.280	0.287	0.298	0.307	0.315	0.322	0.328	0.338	0.346	0.354	0.360	0.366	0.371	0.375	0.380
101,800	12	7	0.254	0.265	0.274	0.282	0.289	0.300	0.309	0.317	0.324	0.330	0.340	0.349	0.356	0.362	0.368	0.373	0.377	0.382
80,000	8	1	0.281	0.292	0.301	0.309	0.316	0.327	0.336	0.344	0.351	0.357	0.367	0.376	0.383	0.389	0.395	0.400	0.404	0.409

Single-layer Conductors—Current Density 1,200 Amp. per Sq. In.

266,800	6	7	0.270	0.281	0.291	0.298	0.305	0.316	0.326	0.333	0.340	0.346	0.356	0.365	0.372	0.378	0.384	0.389	0.393	0.398
4/0	6	1	0.273	0.284	0.294	0.301	0.308	0.319	0.329	0.336	0.343	0.349	0.359	0.368	0.375	0.381	0.387	0.392	0.397	0.401
3/0	6	1	0.278	0.290	0.299	0.307	0.313	0.325	0.334	0.342	0.348	0.354	0.365	0.373	0.380	0.387	0.392	0.397	0.402	0.406
2/0	6	1	0.282	0.294	0.303	0.311	0.317	0.329	0.338	0.346	0.352	0.358	0.369	0.377	0.384	0.391	0.396	0.401	0.406	0.410
1/0	6	1	0.285	0.296	0.306	0.313	0.320	0.332	0.341	0.348	0.355	0.361	0.371	0.380	0.387	0 393	0.399	0.404	0.409	0.413
1	6	1	0.288	0.299	0.308	0.314	0.323	0.334	0.343	0.351	0.358	0.364	0.374	0.382	0.390	0.396	0.402	0.407	0.411	0.415
2	6	1	0.290	0.301	0.310	0.316	0.325	0.336	0.345	0.353	0.360	0.366	0.376	0.384	0.392	0.398	0.403	0.409	0.413	0.417
3	6	1	0.292	0.303	0.312	0.320	0.327	0.338	0.347	0.355	0.362	0.368	0.378	0.386	0.394	0.400	0.406	0.411	0.415	0.419
4	6	1	0.294	0.305	0.315	0.322	0.329	0.340	0.350	0.357	0.364	0.370	0.380	0.389	0.396	0.402	0.408	0.413	0.418	0.422
5	6	1	0.301	0.312	0.321	0.329	0.336	0.347	0.357	0.364	0.371	0.377	0.387	0.396	0.403	0.409	0.415	0.420	0.424	0.429
6	6	1	0.306	0.318	0.327	0.335	0.341	0.353	0.362	0.370	0.376	0.382	0.393	0.401	0.408	0.415	0.420	0.425	0.430	0.434
203,000	8	7	0.268	0.280	0.289	0.297	0.304	0.315	0.324	0.332	0.339	0.344	0.355	0.363	0.370	0.377	0.382	0.387	0.392	0.396
203,200	16	19	0.258	0.270	0.279	0.287	0.293	0.305	0.314	0.322	0.328	0.334	0.344	0.353	0.360	0.366	0.372	0.377	0.382	0.386
211,300	12	7	0.262	0.273	0.283	0.290	0.297	0.308	0.318	0.325	0.332	0.338	0.348	0.357	0.364	0.370	0.376	0.381	0.385	0.390
190,800	12	7	0.265	0.276	0.285	0.293	0.300	0.311	0.320	0.328	0.335	0.341	0.351	0.359	0.366	0.373	0.378	0.383	0.388	0.392
176,900	12	7	0.267	0.278	0.287	0.295	0.302	0.313	0.322	0.330	0.337	0.343	0.353	0.361	0.368	0.375	0.380	0.385	0.390	0.394
159,000	12	7	0.269	0.280	0.290	0.298	0.304	0.315	0.325	0.333	0.339	0.345	0.355	0.364	0.371	0.377	0.383	0.388	0.393	0.397
134,600	12	7	0.273	0.285	0.294	0.302	0.308	0.320	0.329	0.337	0.343	0.349	0.360	0.368	0.375	0.382	0.387	0.392	0.397	0.401
110,800	12	7	0.278	0.290	0.299	0.307	0.313	0.325	0.334	0.342	0.348	0.354	0.364	0.373	0.380	0.386	0.392	0.397	0.402	0.406
101,800	12	7	0.280	0.292	0.301	0.309	0.315	0.327	0.336	0.344	0.350	0.356	0.367	0.375	0.382	0.389	0.394	0.399	0.404	0.408
80,000	8	1	0.294	0.305	0.314	0.322	0.329	0.340	0.349	0.357	0.364	0.370	0.380	0.389	0.396	0.402	0.408	0.413	0.417	0.422

[a] The table values were derived from the equation $x = 2\pi fL$, in which x = the reactance in ohms; L = the inductance in henries per mile of single conductor, and f = the frequency. The reactance at any other frequency than 25 cycles is $f/25$ times the table values. The reactance x' at any spacing D' not given in the table is equal to the reactance x at the next smaller spacing D given in the table plus the quantity $0.1164 \log_{10} D'/D$. Thus $x' = x + 0.1164 \log_{10} D'/D$. Or the reactance in ohms, to be added to that at the next smaller spacing may be taken from table below:

D'/D	1.05	1.10	1.15	1.20	1.25	1.30	1.35	1.40	1.45	1.50	1.55	1.60	1.65	1.70	1.75	1.80	1.85	1.90	1.95	2.00
$x +$	0.002	0.005	0.007	0.009	0.011	0.013	0.015	0.017	0.019	0.020	0.022	0.024	0.025	0.027	0.028	0.030	0.031	0.032	0.034	0.035

[c] See Table 40.

[d] By single-layer conductors is meant conductors with one layer of aluminum over the steel core.

65. 60-cycle Reactance[a] per Mile of Single Conductor—Aluminum Cable, Steel-reinforced

Cir. mils or A.w.g. (B. & S.) alum.	No. of wires		Distance d between centers of conductors[c]																	
	Alum.	Steel	2 ft.	2.5 ft.	3 ft.	3.5 ft.	4 ft.	5 ft.	6 ft.	7 ft.	8 ft.	9 ft.	11 ft.	13 ft.	15 ft.	17 ft.	19 ft.	21 ft.	23 ft.	25 ft.
			60-cycle reactance x in ohms per mile of each conductor of a single-phase, two-phase, or three-phase circuit																	
Multiple-layer Conductors[b]—All Current Densities																				
1,590,000	54	19	0.443	0.470	0.492	0.511	0.527	0.554	0.576	0.595	0.611	0.625	0.650	0.670	0.686	0.701	0.716	0.728	0.739	0.749
1,510,500	54	19	0.446	0.473	0.495	0.514	0.530	0.557	0.579	0.598	0.614	0.628	0.653	0.673	0.690	0.706	0.719	0.731	0.742	0.752
1,431,000	54	19	0.449	0.476	0.499	0.517	0.533	0.561	0.583	0.601	0.618	0.632	0.656	0.676	0.694	0.709	0.722	0.734	0.746	0.756
1,351,500	54	19	0.453	0.480	0.502	0.521	0.537	0.564	0.586	0.605	0.621	0.635	0.660	0.680	0.697	0.713	0.727	0.738	0.749	0.759
1,272,000	54	19	0.456	0.484	0.506	0.524	0.541	0.568	0.590	0.608	0.625	0.639	0.663	0.684	0.701	0.716	0.730	0.742	0.752	0.763
1,192,500	54	19	0.460	0.487	0.510	0.528	0.544	0.572	0.594	0.612	0.628	0.643	0.667	0.688	0.705	0.720	0.734	0.746	0.757	0.767
1,113,000	54	19	0.464	0.492	0.514	0.532	0.549	0.576	0.598	0.616	0.633	0.647	0.671	0.692	0.709	0.724	0.737	0.750	0.761	0.771
1,033,500	54	7	0.469	0.496	0.518	0.537	0.553	0.580	0.602	0.621	0.637	0.654	0.676	0.696	0.714	0.729	0.742	0.754	0.765	0.775
954,000	54	7	0.474	0.501	0.523	0.542	0.559	0.585	0.607	0.626	0.642	0.656	0.681	0.701	0.719	0.734	0.747	0.759	0.770	0.780
900,000	54	7	0.477	0.504	0.527	0.546	0.561	0.588	0.611	0.630	0.646	0.660	0.684	0.705	0.722	0.737	0.751	0.763	0.774	0.784
874,000	54	7	0.479	0.506	0.518	0.547	0.563	0.590	0.612	0.631	0.647	0.662	0.686	0.706	0.723	0.739	0.752	0.764	0.775	0.785
795,000	54	7	0.485	0.512	0.534	0.553	0.569	0.596	0.618	0.637	0.653	0.667	0.692	0.712	0.729	0.745	0.758	0.770	0.781	0.791
795,000	26	7	0.483	0.510	0.532	0.550	0.567	0.594	0.616	0.635	0.651	0.665	0.689	0.710	0.727	0.742	0.756	0.768	0.779	0.789
795,000	30	19	0.477	0.504	0.526	0.545	0.561	0.588	0.611	0.629	0.645	0.660	0.684	0.704	0.722	0.737	0.750	0.762	0.774	0.783
715,500	54	7	0.491	0.518	0.541	0.559	0.576	0.602	0.625	0.644	0.660	0.674	0.698	0.719	0.736	0.751	0.765	0.777	0.788	0.798
715,500	26	7	0.489	0.516	0.538	0.557	0.573	0.600	0.622	0.641	0.657	0.671	0.696	0.716	0.733	0.748	0.762	0.774	0.785	0.795
715,500	30	19	0.483	0.510	0.533	0.552	0.568	0.595	0.617	0.636	0.652	0.666	0.691	0.711	0.728	0.743	0.757	0.769	0.780	0.790
666,600	54	7	0.496	0.523	0.545	0.564	0.580	0.607	0.629	0.648	0.664	0.678	0.703	0.723	0.740	0.756	0.769	0.781	0.792	0.802
636,000	54	7	0.498	0.526	0.547	0.566	0.582	0.610	0.631	0.650	0.667	0.681	0.705	0.725	0.743	0.758	0.772	0.784	0.795	0.805
636,000	26	7	0.496	0.523	0.546	0.564	0.580	0.607	0.630	0.648	0.664	0.679	0.703	0.723	0.741	0.756	0.769	0.782	0.792	0.803
636,000	30	19	0.491	0.518	0.540	0.559	0.575	0.602	0.624	0.643	0.659	0.673	0.697	0.718	0.735	0.751	0.746	0.774	0.787	0.797
605,000	54	7	0.501	0.529	0.551	0.569	0.585	0.613	0.635	0.653	0.670	0.684	0.708	0.729	0.746	0.761	0.775	0.787	0.798	0.808
605,000	26	7	0.499	0.526	0.548	0.567	0.583	0.610	0.632	0.651	0.667	0.682	0.706	0.726	0.744	0.759	0.773	0.784	0.796	0.806
556,500	26	7	0.504	0.531	0.553	0.572	0.588	0.615	0.638	0.656	0.672	0.687	0.711	0.731	0.748	0.764	0.777	0.789	0.800	0.811
556,500	30	7	0.498	0.526	0.548	0.566	0.582	0.610	0.632	0.650	0.667	0.681	0.705	0.726	0.743	0.758	0.772	0.784	0.795	0.805

477,000	26	7	0.514	0.541	0.563	0.581	0.598	0.625	0.647	0.665	0.682	0.696	0.720	0.741	0.758	0.773	0.787	0.799	0.810	0.820
477,000	30	7	0.508	0.535	0.557	0.576	0.592	0.619	0.641	0.660	0.676	0.690	0.715	0.735	0.752	0.768	0.781	0.794	0.804	0.814
397,500	26	7	0.525	0.552	0.574	0.593	0.609	0.636	0.658	0.677	0.693	0.707	0.732	0.752	0.769	0.780	0.798	0.810	0.821	0.831
397,500	30	7	0.519	0.546	0.568	0.587	0.603	0.630	0.652	0.671	0.685	0.701	0.726	0.746	0.763	0.779	0.792	0.804	0.813	0.826
336,400	26	7	0.534	0.562	0.584	0.602	0.619	0.646	0.668	0.687	0.703	0.717	0.742	0.762	0.779	0.794	0.808	0.820	0.831	0.841
336,400	30	7	0.529	0.556	0.578	0.597	0.613	0.640	0.662	0.681	0.697	0.712	0.736	0.756	0.774	0.789	0.802	0.814	0.825	0.835
300,000	26	7	0.542	0.569	0.591	0.610	0.626	0.653	0.675	0.694	0.710	0.724	0.748	0.769	0.786	0.801	0.813	0.827	0.838	0.848
300,000	30	7	0.536	0.563	0.585	0.604	0.620	0.647	0.669	0.688	0.704	0.718	0.743	0.763	0.780	0.796	0.809	0.821	0.832	0.842
266,800	26	7	0.549	0.576	0.598	0.617	0.633	0.660	0.682	0.701	0.717	0.731	0.756	0.776	0.793	0.802	0.822	0.834	0.845	0.855

Single-layer Conductors[d]—Current Density 0 Amp. per Sq. In.

266,800	6	7	0.550	0.578	0.600	0.618	0.635	0.662	0.684	0.702	0.719	0.733	0.757	0.778	0.795	0.810	0.824	0.836	0.847	0.857
4/0	6	1	0.608	0.635	0.657	0.676	0.692	0.719	0.741	0.760	0.776	0.790	0.815	0.835	0.852	0.868	0.881	0.893	0.904	0.914
3/0	6	1	0.624	0.651	0.673	0.692	0.708	0.735	0.757	0.776	0.792	0.806	0.831	0.851	0.869	0.884	0.897	0.909	0.920	0.930
2/0	6	1	0.638	0.665	0.688	0.706	0.722	0.750	0.772	0.790	0.806	0.821	0.845	0.866	0.883	0.898	0.912	0.924	0.935	0.945
1/0	6	1	0.652	0.679	0.701	0.720	0.736	0.763	0.785	0.804	0.820	0.834	0.859	0.879	0.897	0.912	0.925	0.937	0.948	0.958
1	6	1	0.664	0.691	0.714	0.732	0.748	0.776	0.798	0.816	0.832	0.847	0.871	0.892	0.909	0.924	0.938	0.950	0.961	0.971
2	6	1	0.676	0.704	0.726	0.744	0.760	0.788	0.810	0.828	0.845	0.859	0.883	0.904	0.921	0.936	0.950	0.962	0.973	0.983
3	6	1	0.688	0.716	0.738	0.756	0.773	0.800	0.822	0.840	0.857	0.871	0.895	0.916	0.933	0.948	0.962	0.974	0.985	0.995
4	6	1	0.701	0.728	0.751	0.769	0.785	0.812	0.835	0.853	0.869	0.884	0.908	0.929	0.946	0.961	0.975	0.987	0.998	1.01
5	6	1	0.714	0.741	0.763	0.782	0.798	0.825	0.847	0.866	0.882	0.896	0.921	0.941	0.958	0.973	0.987	0.999	1.01	1.02
6	6	1	0.727	0.754	0.777	0.795	0.811	0.838	0.861	0.879	0.895	0.910	0.934	0.955	0.972	0.987	1.00	1.01	1.02	1.03
203,000	8	7	0.567	0.593	0.616	0.634	0.651	0.678	0.700	0.719	0.735	0.749	0.774	0.794	0.811	0.826	0.840	0.852	0.863	0.873
203,200	16	19	0.542	0.569	0.592	0.610	0.627	0.653	0.676	0.694	0.711	0.725	0.749	0.769	0.787	0.802	0.815	0.828	0.838	0.849
211,300	12	7	0.551	0.578	0.601	0.619	0.635	0.662	0.685	0.703	0.719	0.734	0.758	0.779	0.796	0.811	0.824	0.837	0.847	0.858
190,800	12	7	0.557	0.584	0.607	0.625	0.641	0.668	0.691	0.709	0.725	0.740	0.764	0.785	0.802	0.817	0.831	0.843	0.854	0.864
176,900	12	7	0.562	0.589	0.611	0.630	0.646	0.673	0.695	0.714	0.730	0.745	0.769	0.789	0.806	0.821	0.835	0.847	0.858	0.868

[a] The table values were derived from the equation $x = 2\pi fL$, in which x = the reactance in ohms; L = the inductance in henries per mile of single conductor; and f = the frequency. The reactance at any frequency other than 60 cycles is $f/60$ times the table values. The reactance x' at any spacing D' not given in the table is equal to the reactance x at the next smaller spacing D given in the table plus the quantity $0.2794 \log_{10} D'/D$. Thus $x' = x + 0.2794 \log_{10} D'/D$. Or the reactance in ohms to be added to that at the next smaller spacing may be taken from table below.

D/D	1.05	1.10	1.15	1.20	1.25	1.30	1.35	1.40	1.45	1.50	1.55	1.60	1.65	1.70	1.75	1.80	1.85	1.90	1.95	2.00
$x+$	0.006	0.012	0.017	0.022	0.027	0.032	0.036	0.041	0.045	0.049	0.053	0.057	0.061	0.064	0.068	0.071	0.075	0.078	0.081	0.084

[b] By multiple layer conductors is meant conductors with two or more layers of aluminum over the steel core.
[c] See Table 40.
[d] By single layer conductors is meant conductors with one layer of aluminum over the steel core.

60-cycle Reactance[a] per Mile of Single Conductor—Steel-reinforced Aluminum Cable (*Continued*)

Cir. mils or A.w.g. (B. & S.) alum.	No. of wires		Distance d between centers of conductors[c]																
	Alum.	Steel	2 ft.	2.5 ft.	3 ft.	3.5 ft.	4 ft.	5 ft.	6 ft.	7 ft.	8 ft.	9 ft.	11 ft.	13 ft.	15 ft.	17 ft.	19 ft.	21 ft.	23 ft.	25 ft.
			60-cycle reactance x in ohms per mile of each conductor of a single-phase, two-phase, or three-phase circuit																
Single-layer Conductors[d]—Current Density 0 Amp. per Sq. In.—(*Continued*)																			
159,000	12	7	0.568	0.595	0.618	0.636	0.653	0.679	0.702	0.720	0.737	0.751	0.775	0.795	0.813	0.828	0.841	0.854	0.865	0.875
134,600	12	7	0.578	0.605	0.628	0.646	0.662	0.690	0.712	0.730	0.748	0.761	0.785	0.806	0.823	0.838	0.852	0.864	0.875	0.885
110,800	12	7	0.590	0.617	0.639	0.658	0.674	0.701	0.723	0.742	0.759	0.773	0.797	0.817	0.835	0.850	0.863	0.875	0.887	0.897
101,800	12	7	0.595	0.622	0.645	0.663	0.769	0.706	0.729	0.747	0.763	0.778	0.802	0.823	0.840	0.855	0.869	0.881	0.892	0.902
80,000	8	1	0.663	0.690	0.712	0.731	0.747	0.774	0.796	0.815	0.831	0.845	0.870	0.890	0.907	0.923	0.936	0.948	0.959	0.969
Single-layer Conductors[d]—Current Density 600 Amp. per Sq. In.																			
266,800	6	7	0.568	0.595	0.618	0.636	0.652	0.679	0.702	0.720	0.736	0.751	0.775	0.796	0.813	0.828	0.842	0.854	0.865	0.875
4/0	6	1	0.628	0.655	0.677	0.696	0.712	0.739	0.761	0.780	0.796	0.810	0.835	0.855	0.872	0.888	0.901	0.913	0.924	0.934
3/0	6	1	0.638	0.665	0.687	0.706	0.722	0.749	0.771	0.790	0.806	0.820	0.845	0.865	0.883	0.898	0.911	0.923	0.934	0.944
2/0	6	1	0.648	0.676	0.698	0.716	0.733	0.760	0.782	0.800	0.817	0.831	0.855	0.876	0.893	0.908	0.922	0.934	0.945	0.955
1/0	6	1	0.659	0.686	0.708	0.727	0.743	0.770	0.793	0.811	0.827	0.842	0.866	0.886	0.904	0.919	0.932	0.944	0.955	0.966
1	6	1	0.670	0.698	0.720	0.738	0.754	0.782	0.804	0.822	0.838	0.853	0.877	0.898	0.915	0.930	0.944	0.956	0.967	0.977
2	6	1	0.681	0.708	0.730	0.749	0.765	0.792	0.814	0.833	0.849	0.863	0.888	0.908	0.926	0.941	0.954	0.966	0.977	0.987
3	6	1	0.691	0.719	0.741	0.759	0.776	0.803	0.825	0.843	0.860	0.874	0.898	0.919	0.936	0.951	0.965	0.977	0.988	0.998
4	6	1	0.702	0.730	0.752	0.770	0.786	0.814	0.836	0.854	0.871	0.885	0.909	0.930	0.947	0.962	0.976	0.988	0.999	1.01
5	6	1	0.716	0.743	0.765	0.783	0.800	0.827	0.849	0.868	0.884	0.898	0.923	0.943	0.960	0.975	0.989	1.00	1.01	1.02
6	6	1	0.730	0.757	0.779	0.798	0.814	0.841	0.863	0.882	0.898	0.912	0.937	0.957	0.975	0.990	1.00	1.02	1.03	1.04
203,000	8	7	0.580	0.604	0.627	0.645	0.662	0.689	0.711	0.729	0.746	0.760	0.785	0.805	0.822	0.837	0.848	0.863	0.874	0.884
203,200	16	19	0.553	0.580	0.602	0.621	0.638	0.664	0.687	0.705	0.722	0.736	0.760	0.780	0.798	0.813	0.826	0.838	0.849	0.860
211,300	12	7	0.562	0.589	0.611	0.630	0.646	0.673	0.696	0.714	0.730	0.745	0.770	0.789	0.807	0.822	0.835	0.847	0.858	0.869
190,800	12	7	0.568	0.595	0.618	0.636	0.652	0.679	0.702	0.720	0.736	0.751	0.775	0.795	0.813	0.827	0.841	0.854	0.864	0.875
176,900	12	7	0.573	0.600	0.622	0.641	0.657	0.684	0.706	0.725	0.741	0.756	0.780	0.800	0.817	0.832	0.846	0.858	0.869	0.880
159,000	12	7	0.579	0.606	0.628	0.647	0.664	0.690	0.713	0.731	0.748	0.762	0.786	0.806	0.824	0.839	0.852	0.864	0.876	0.886
134,600	12	7	0.589	0.616	0.639	0.657	0.673	0.700	0.723	0.741	0.757	0.772	0.796	0.817	0.834	0.849	0.863	0.875	0.886	0.896
110,800	12	7	0.601	0.628	0.650	0.669	0.685	0.712	0.734	0.753	0.769	0.784	0.808	0.828	0.846	0.861	0.874	0.886	0.898	0.908
101,800	12	7	0.606	0.633	0.656	0.674	0.690	0.717	0.740	0.758	0.774	0.789	0.813	0.834	0.851	0.866	0.880	0.892	0.903	0.913
80,000	8	1	0.674	0.701	0.724	0.742	0.758	0.785	0.808	0.826	0.842	0.857	0.881	0.901	0.919	0.934	0.947	0.959	0.970	0.981

Single-layer Conductors[d]—Current Density 1,200 Amp. per Sq. In.

266,800	6	7	0.648	0.675	0.697	0.716	0.732	0.759	0.781	0.800	0.816	0.830	0.855	0.875	0.892	0.907	0.921	0.933	0.944	0.954
4/0	6	1	0.655	0.682	0.705	0.723	0.739	0.766	0.789	0.807	0.823	0.838	0.862	0.883	0.900	0.915	0.929	0.941	0.952	0.962
3/0	6	1	0.668	0.695	0.717	0.736	0.752	0.779	0.802	0.820	0.836	0.851	0.875	0.895	0.913	0.928	0.941	0.953	0.964	0.975
2/0	6	1	0.677	0.705	0.727	0.745	0.762	0.789	0.811	0.829	0.846	0.860	0.884	0.905	0.922	0.937	0.951	0.963	0.974	0.984
1/0	6	1	0.684	0.711	0.734	0.752	0.768	0.796	0.818	0.836	0.852	0.867	0.891	0.912	0.929	0.944	0.958	0.970	0.981	0.991
1	6	1	0.690	0.717	0.740	0.754	0.774	0.802	0.824	0.842	0.858	0.873	0.897	0.918	0.935	0.950	0.964	0.976	0.987	0.997
2	6	1	0.695	0.722	0.744	0.758	0.779	0.806	0.828	0.847	0.863	0.877	0.902	0.922	0.940	0.955	0.968	0.980	0.991	1.00
3	6	1	0.700	0.727	0.749	0.768	0.784	0.811	0.833	0.852	0.868	0.882	0.907	0.927	0.944	0.960	0.973	0.985	0.996	1.01
4	6	1	0.706	0.733	0.755	0.774	0.790	0.817	0.839	0.858	0.874	0.888	0.913	0.933	0.950	0.966	0.979	0.991	1.00	1.01
5	6	1	0.722	0.749	0.771	0.790	0.806	0.833	0.855	0.874	0.890	0.904	0.929	0.949	0.967	0.982	0.995	1.01	1.02	1.03
6	6	1	0.735	0.762	0.785	0.803	0.819	0.846	0.869	0.887	0.903	0.918	0.942	0.963	0.980	0.995	1.01	1.02	1.03	1.04
203,000	8	7	0.625	0.651	0.674	0.693	0.709	0.736	0.758	0.777	0.793	0.807	0.831	0.852	0.869	0.884	0.898	0.910	0.921	0.931
203,200	16	19	0.600	0.627	0.650	0.668	0.685	0.711	0.734	0.752	0.769	0.783	0.807	0.828	0.845	0.860	0.874	0.886	0.897	0.907
211,300	12	7	0.609	0.636	0.659	0.677	0.693	0.720	0.743	0.761	0.777	0.792	0.816	0.837	0.854	0.869	0.883	0.895	0.906	0.916
190,800	12	7	0.615	0.642	0.665	0.683	0.699	0.726	0.749	0.767	0.783	0.798	0.822	0.843	0.860	0.875	0.889	0.901	0.912	0.922
176,900	12	7	0.620	0.647	0.669	0.688	0.704	0.731	0.753	0.772	0.788	0.803	0.827	0.847	0.864	0.880	0.893	0.905	0.916	0.926
159,000	12	7	0.626	0.653	0.676	0.694	0.711	0.737	0.760	0.779	0.795	0.809	0.833	0.854	0.871	0.886	0.900	0.912	0.923	0.933
134,600	12	7	0.636	0.664	0.686	0.704	0.720	0.748	0.770	0.788	0.805	0.819	0.843	0.864	0.881	0.896	0.910	0.922	0.933	0.943
110,800	12	7	0.648	0.675	0.697	0.716	0.733	0.759	0.782	0.800	0.817	0.831	0.855	0.875	0.893	0.908	0.921	0.933	0.945	0.955
101,800	12	7	0.653	0.680	0.703	0.721	0.737	0.765	0.787	0.805	0.821	0.836	0.860	0.881	0.898	0.913	0.927	0.939	0.950	0.960
80,000	8	1	0.704	0.732	0.754	0.772	0.789	0.816	0.838	0.856	0.873	0.887	0.911	0.932	0.949	0.964	0.978	0.990	1.001	1.011

[a] The table values were derived from the equation $x = 2\pi fL$, in which x = the reactance in ohms; L = the inductance in henries per mile of single conductor, and f = the frequency. The reactance at any other frequency than 60 cycles is $f/60$ times the table values. The reactance x' at any spacing D' not given in the table is equal to the reactance x at the next smaller spacing D given in the table plus the quantity $0.2794 \log_{10} D'/D$. Thus $x' = x + 0.2794 \log_{10} D'/D$. Or the reactance in ohms, to be added to that at the next smaller spacing may be taken from table below:

D/D	1.05	1.10	1.15	1.20	1.25	1.30	1.35	1.40	1.45	1.50	1.55	1.60	1.65	1.70	1.75	1.80	1.85	1.90	1.95	2.00
$x+$	0.006	0.012	0.017	0.022	0.027	0.032	0.036	0.041	0.045	0.049	0.053	0.057	0.061	0.064	0.068	0.071	0.075	0.078	0.081	0.084

[c] See Table 40.

[d] By single-layer conductors is meant conductors with one layer of aluminum over the steel core.

66. Phototubes
(RCA Manufacturing Co.)

Type	Name	Principal use	Cathode window area, sq. in.	Luminous sensitivity μamp./lumen			Spectral sensitivity curve	Gas amplification factor[b]	Direct interelectrode capacitance, μμf.	Max. ambient temperature, °C.	Max. anode supply d-c or peak a-c volts	Max. anode current[c] μamp.	Min. d-c load resistance, megohms, for					
				0 cycles	1,000[a] cycles	5,000[a] cycles							Up to 75-volt supply		90-volt supply		250-volt supply	500-volt supply
													Below 3.5 μamp.	Above 3.5 μamp.	Below 2 μamp.	Above 2 μamp.		
868	Gas phototube	Sound reproduction	1	65	61	57	C-1	Not over 7	2.5	100	90	20	0	0.1	0.1	2.5		
917	Vacuum phototube with anode cap	Relays and measurements	1	20	20	20	C-2	.....	2.0	100	500	30	..	...	...	...	1	10
918	Gas phototube	Sound reproduction	1	110	104	96	C-2	Not over 10	2.5	100	90	20	0	0.1	1	4		
919	Vacuum phototube with cathode cap	Relays and measurements	1	20	20	20	C-2	.....	2.0	100	500	30	...	...	...	...	1	10
920	Twin phototube, gas type	Sound reproduction	0.3	75	70	65	C-1	Not over 10	1.5[d]	100	90	10	0	0.1	1	4		
921	Gas phototube cartridge type	Sound reproduction	0.4	100	94	87	C-2	Not over 9	1.0	100	90	20	0	0.1	1	4		
922	Vacuum phototube, cartridge type	Relays and measurements	0.4	20	20	20	C-2	.....	0.5	100	500	30	..	...	...	...	1	10

923	Gas phototube	Sound reproduction	0.4	100	94	87	C-2	Not over 9	2.0	100	90	20	0	0.1	1	4		
924	Gas phototube, end type	Relays	0.2	55	Less than 55	Less than 55	C-1	Not over 8.5	2.5	100	90	15	0	0.1	0.1	2.5		
925	Vacuum phototube	Relays	0.4	15	15	15	C-1	.....	1.0	100	250	20	..	..	.	...	1	
926	Vacuum phototube, cartridge type	Colorimetry	0.4	6.5	6.5	6.5	C-3	.....	0.5	100	500	20	..	...	...	...	1	10
927	Gas phototube	Sound reproduction	0.4	75	70	65	C-1	Not over 7	2.0	100	90	2	0	...	0.1			
928	Gas phototube, nondirectional type	Relays	0.7	65	Less than 65	Less than 65	C-1	Not over 10	3.0	100	90	15	0	0.1	1	4		
929	Vacuum phototube	Relays and measurements	0.6	45	45	45	C-4	.....	2.5	50	250	20	..	...	...	...	1	
930	Gas phototube	Sound reproduction	0.6	100	94	87	C-2	Not over 9	2.5	100	90	20	0	0.1	1	4		

[a] These sensitivity values are measured with a light input varied sinusoidally about a mean value from zero to a maximum of twice the mean. The sensitivity values shown are the ratio of the amplitude of variation in the current output to the amplitude of variation in the light input. The light source was a Mazda projection lamp operating at a filament color temperature of 2870°K. Sensitivity of the gas phototubes was measured with a 90-volt supply, a 1-megohm load, and a mean light input of 0.015 lumen. Sensitivity of the vacuum phototubes was measured with a 250-volt supply, a 1-megohm load, and a mean light input of 0.1 lumen.

[b] Ratio of sensitivity at maximum anode voltage to sensitivity at a voltage sufficiently low (approximately 25 volts) to eliminate gas ionization effects.

[c] On basis of the use of a sensitive cathode area ½ in. in diameter.

[d] Between cathode and anode of each unit. Capacitance between cathodes = 1.6 $\mu\mu$f.; between anodes = 0.36 $\mu\mu$f.

67. Phanotrons—Gaseous or Mercury-vapor Thermionic Rectifier Tube

(General Electric Co.)

Type No.	No. of electrodes	Cathode		Anode			Temp. rang condensed-mercury,°C
		Volts	Amp.	Peak volts	Peak amp.	Average amp.	
FG-32	2	5.0	4.5	1,000	15	2.5	40–80
FG-104	2	5.0	10	3,000	40	6.4	40–80
FG-166	2	2.5	100	1,500	75	20	20–60
FG-190	3	2.5	12	175	5	1.25	−20–+50[b]
GL-266-B	2	5.0	30	22,000	20 40[a]	5 10[a]	30–40
FG-280	2	5.0	10	2,000	40	6.4	40–80
GL-575-A	2	5.0	10	15,000	6	1.5	20–60
GL-673	2	5.0	10	15,000	6	1.5	20–60
GL-816	2	2.5	2	5,000		0.125	
GL-857-B	2	5	30	22,000	20 40[a]	5 10[a]	30–40
GL-866-A/866	2	2.5	5	10,000	1	0.25	20–60
GL-869-B	2	5	18	20,000 15,000[a]	15	2.5 5.0[a]	30–40
GL-870-A	2	5	65	16,000		75.0	35–40
GL-872-A/872	2	5	7.5	10,000	5	1.25	20–60
GL-8008	2	5	7.5	10,000	5	1.25	20–60
OY4/OY4-G	2	Cold cathode		300	0.5	0.075	
OZ4/OZ4-G	2	Cold cathode		300	0.2	0.075	

[a] Quadrature operation.

[b] This tube is inert-gas-filled, and the temperature rating is expressed in terms of th ambient temperature range over which the tubes will operate.

68. Thyratron Tubes
(General Electric Co.)

Type No.	No of electrodes	Cathode		Anode			Starting grid voltage	Temp. range condensed mercury, °C.
		Volts	Amp.	Peak volts	Peak amp.	Average amp.		
GL-3C23	3	2.5	7.0	1,250	6.0	1.5	Neg.	−40–+80
GL-3C45	3	6.3	2.1	3,000	35	0.045	....	−40–+90[a]
FG-17	3	2.5	5.0	5,000	2.0	0.5	Neg.	40–80
FG-27-A	3	5.0	4.5	1,000	10.0	2.5	Neg.	40–80
FG-33	3	5.0	4.5	1,000	15.0	2.5	Pos.	35–80
FG-41	3	5.0	20.0	10,000	75.0	12.5	Neg.	40–65
FG-57	3	5.0	4.5	1,000	15.0	2.5	Neg.	40–80
FG-67	3	5.0	4.5	1,000	15.0	2.5	Var.	40–80
FG-81-A	3	2.5	5.0	500	2.0	0.5	Neg.	−20–+50[b]
FG-95	4	5.0	4.5	1,000	15.0	2.5	Var.	40–80
		5.5[c]	5.0	1,000	40.0	0.5	Var.	40–80
FG-97	4	2.5	5.0	1,000	2.0	0.5	Var.	40–80
FG-98-A	4	2.5	5.0	500	2.0	0.5	Neg.	−20–+50[b]
FG-105	4	5.0	10.0	2,500	40.0	6.4	Var.	40–80
		5.5[d]	11.0	750	77.0	2.5	Var.	30–95
		5.5[d]	10.0	10,000	16.0	4.0	Var.	25–50
FG-154	4	5.0	7.0	500	10.0	2.5	Neg.	−20–+50
FG-172	4	5.0	10.0	2,000	40.0	6.4	Var.	40–80
		5.5[d]	11.0	750	77.0	2.5	Var.	30–95
FG-178-A	3	2.5	2.25	500	0.500	0.125	Neg.	−20–+50[b]
GL-393-A	3	2.5	7.0	1,250	6.0	1.5	Neg.	−40–+80
GL-414	4	5.0	20.0	2,000	100.0	12.5	Neg.	40–80
GL-502-A	4	6.3	0.6	1,300	0.500	0.100	Neg.	−55–+90[a]
GL-546	4	6.3	0.15	500	0.100	0.020	Neg.	−40–+80
GL-627	3	2.5	6.0	2,500	2.5	0.64	Neg.	+25–+70
GL-672	4	5.0	6.0	1,500	30	2.5	Neg.	+40–+80
GL-678	3	5.0	7.5	15,000	6.0	1.6	Neg.	+25–+50
GL-884	3	6.3	0.6	350	0.300	0.075	Neg.	
GL-885	3	2.5	1.4	350	0.300	0.075	Neg.	
GL-2050	4	6.3	0.6	1,300	0.500	0.100	Neg.	
GL-2051	4	6.3	0.6	700	0.375	0.075	Neg.	

[a] Ambient temperature.

[b] These tubes are inert-gas-filled, and the temperature ratings are expressed in terms of the ambient temperature range over which the tubes will operate.

[c] These ratings apply only when the tube is used for ignitor firing.

[d] These ratings apply only when the tube is used in thyratron welding-control service.

69. Ignitron Tubes
(General Electric Co.)

Type No.	Supply volts	Maximum ratings				Type of cooling
		Kva. demand	Corresponding average anode current, amp.	Maximum average anode current, amp.	Corresponding kva. demand	
FG-235-A[a]	250–600 r.m.s.	1,200	75.6	140	400	Water
FG-238-B[b,c]	2,400 r.m.s.	2,400	135	207	1,105	Water
FG-258-A[a]	250–600 r.m.s.	2,400	192	355	800	Water
FG-259-B[b,c]	2,400 r.m.s.	1,200	75	113	600	Water
FG-271[a]	250–600 r.m.s.	600	30.2	56.0	200	Water
GL-415[a]	250–600 r.m.s.	300	12.1	22.4	100	Water
GL-427	125 d-c	Peak amp. = 30, average amp. = 5				

[a] Ratings are for voltages of 600 volts r.m.s. and below. Ignitor requirements for all welding-control types are 200 volts and 30 amp.

[b] Typical ignitor requirements for power-rectifier ignitrons are 75 to 125 volts, 15 to 20 amp. Maximum requirements are 150 volts, 40 amp.

[c] In addition to ratings given above for welder-control service, the FG-238-B and FG- 259-B may be used as power rectifiers in the 125 to 900 d-c voltage fields.

70. Cold-cathode Voltage-regulator Tubes
(General Electric Co.)

Type No.	Starting supply voltage, d-c min.	Operating voltage maintained, d-c approx.	Operating current, milliamp.		Voltage-regulation volts
			Min.	Max.	
OA3/VR-75	105	75	5	40	5
OB3/VR-90	125	90	5	40	8
OC3/VR-105	133	105	5	40	2
OD3/VR-150	185	150	5	40	4
874	125	90	10	50	
OA2	185	150	5	30	2
OB2	133	105	5	30	1

71. Kenotrons—High-vacuum Rectifier Tubes

(General Electric Co.)

Type No.	Cathode		Anode			Voltage-drop volts
	Volts	Amp.	Max. inverse volts	Max. amp.	Average amp.	
GL-2B22	6.3	0.75	100			
GL-2B23	6.3	0.3	150	0.030		
2X2A/879	2.5	1.75	12,500	0.100		
KC-4	20	24.5	150,000	0.750		
5R4-GY	5.0	2.0	2,800	0.650		
FP-85-A	10	5.0	20,000	0.100		
GL-217-C	10	3.25	7,500	0.600		210
GL-218	11	14.75	50,000	0.750		
GL-219	22	24.5	50,000	2.5		
FP-400	4	2.25	100	0.025		
GL-411	10	14.5	100,000	0.750		
GL-836	2.5[a]	5.0	5,000	1.0	0.25	45
GL-1616	2.5	5.0	5,500	0.800	0.13	75
GL-1641	5.0	3.0	2,120	0.250	.....	61
GL-8013-A	2.5	5.0	40,000	0.150	0.020	
GL-8016	1.25	0.2	10,000	0.0075	0.002	
GL-8020	5.0	6.0	40,000	0.750	0.100	200
	5.8[b]	.....	12,500[b]			
GL-9004	6.3	0.15	117			
GL-9005	3.6	0.165	117			
GL-9006	6.3	0.15	750	0.015		

[a] Heater-type cathode.

[b] Surge-limiting diode operation.

72. Characteristics and Ratings of

(General

Tube type	Classification by construction	Base connections (Fig. 1.)	Outline drawing (Fig. 2.)	Type cathode	Filament supply	Filament volts	Filament amp.	Max. plate volts	Max. screen volts	Capacitance, $\mu\mu$f.		
										Input	Output	Grid plate
Diodes												
5U4-G	Full-wave high-vacuum rectifier	5T	16-3	Fil.	A-c	5.0	3.0	Rms. voltage per plate = 450 volts				
5Y3-GT	Full-wave high-vacuum rectifier	5T	9-11	Fil.	A-c	5.0	2.0	Rms. voltage per plate = 350 volts				
6AL5	Twin diode	6BT	5-1	Htr.	A-c	6.3	0.3	R.m.s. voltage per plate = 150				
6H6	Twin diode	7Q	8-5	Htr.	A-c	6.3	0.3	R.m.s. voltage per plate = 100				
6X5-GT	Full-wave high-vacuum rectifier	6S	9-11	Htr.	A-c	6.3	0.6	R.m.s. voltage per plate (choke in				
35W4	Half-wave high-vacuum rectifier	5BQ	5-3	Htr.	A-c	35.0	0.15	Without panel lamp: max. d-c outp				
						22.0	0.15	With panel lamp: max. d-c output				
35Z5-GT	Half-wave high-vacuum rectifier	6AD	9-11	Htr.	A-c	35.0	0.15	Without panel lamp: r.m.s. plate				
								With panel lamp: r.m.s. plate volt				
117Z6-GT	High-vacuum rectifier doubler	7Q	9-11	Htr.	A-c	117	0.075	R.m.s. voltage per plate = 11				
Triodes												
6C4	Detector amplifier triode	6BG	5-2	Htr.	A-c	6.3	0.15	300	....	1.8[a]	1.3[a]	1.6[a]
6J5	Detector amplifier triode	6Q	8-1	Htr.	A-c	6.3	0.3	300	....	3.4	3.6	3.4
Pentodes												
1L4	Sharp-cut-off r.f. amplifier pentode	.....	.....	Fil.	D-c	1.4	0.05	110	90	3.6[a]	7.5[a]	0.008[a]
1T4	Remote-cut-off r.f. amplifier pentode	6AR	5-2	Fil.	D-c	1.4	0.05	90	67.5	3.6	7.5	0.01
1U4	R.f. amplifier pentode	6AR	5-2	Fil.	D-c	1.4	0.05	110	110	3.6	7.5	0.008
3Q4	Power amplifier pentode	7BA	5-2	Fil.	D-c	1.4	0.1	90	90	Parallel filaments		
						2.8	0.05	90	90	Series filaments		

[a] Without external shield.

[b] Approximate.

Preferred Types of Vacuum Tubes

Electric Co.)

Type of service	Neg. grid volts	Screen volts	Screen milli-amp.	Plate volts	Plate milli-amp.	R_p, ohms	G_m, μmhos	μ factor	Load for rated output, ohms	Power output, watts

max.; maximum d-c output = 225 ma. max.; peak current per plate = 675 ma. max.; peak inverse voltage = 1,550 volts max.

max.; maximum d-c output = 125 ma.; peak current per plate = 375 ma.; peak inverse voltage = 1,400 volts max.

volts; max. d-c output = 9.0 ma.; peak current per plate = 54 ma.; peak inverse voltage = 420

volts; max. d-c output = 8 ma.; peak current per plate = 48 ma.; peak inverse voltage = 420 volts

put) = 450 volts; max. d-c output = 70 ma.; peak current per plate = 210 ma.; peak inverse voltage = 1,250 volts

put = 100 ma.; max. peak inverse plate voltage = 330; max. peak plate current = 600 ma.

= 80 ma.; max. peak inverse plate voltage = 330; max. peak plate current = 600 ma.

voltage = 235 volts; max. d-c output = 100 ma.; peak plate current = 600 ma.; peak inverse voltage = 700 volts

age = 235 volts; max. d-c output = 60 ma.; peak inverse voltage = 700 volts

half-wave rectifier max. r.m.s. volts per plate = 235; max. d-c output = 60 ma.; peak current per plate = 360 ma.; peak inverse voltage = 700 volts

Class A amplifier	8.5	.....	.....	250	10.5	7,700	2,200	17		
Class A amplifier	8.0	.....	.....	250	9.0	7,700	2,600	20		

Class A amplifier	0.0	90	2.0	90	4.5	350,000	1,025			
Class A amplifier	0.0	67.5	1.4	90	3.5	500,000[b]	900			
Class A amplifier	0.0	67.5	1.5	67.5	3.4	250,000[b]	875			
Class A amplifier	0.0	45	0.7	45	1.7	350,000[b]	700			
Class A amplifier	0.0	90	0.45	90	1.6	1,500,000[b]	900			
Class A amplifier	4.5	90	2.1[c]	90	9.5[c]	100,000[b]	2,150	...	10,000	0.27
Class A amplifier	4.5	90	1.7[c]	90	7.7[c]	120,000[b]	2,000	...	10,000	0.24

[c] Zero signal.

Characteristics and Ratings of

Tube type	Classification by construction	Base connections (Fig. 1.)	Outline drawing (Fig. 2.)	Type cathode	Filament supply	Filament volts	Filament amp.	Max. plate volts	Max. screen volts	Capacitance $\mu\mu$f. Input	Output	Grid plate
3S4	Power amplifier pentode	7BA	5–2	Fil.	D-c	1.4	0.10	90	67.5	Parallel filaments		
						1.4	0.1	90	67.5	Parallel filaments		
						2.8	0.05	90	67.5	Series filaments		
						2.8	0.05	90	67.5	Series filaments		
6AC7/1852	Sharp-cut-off high-G_m amplifier pentode	8N	8–1	Htr.	A-c	6.3	0.45	300	150	Bias resistors 160 ohms		
6BA6	Remote-cut-off r.f. amplifier pentode	7CC	5–2	Htr.	A-c	6.3	0.30	300	125	5.5[a]	5.0[a]	0.0035[a]
6K6-GT	Power-amplifier pentode	7S	9–11	Htr.	A-c	6.3	0.4	315	285	Single tube		
								315	285	2 tubes, push-pull		
6L6-GA	Beam power amplifier	7AC	14–3	Htr.	A-c	6.3	0.9	360	270	Single tube		
								360	270	Single tube		
								360	270	2 tubes		
								360	270	2 tubes		
								360	270	2 tubes		
6SG7	Semiremote-cut-off high-G_m amplifier pentode	8BK	8–1	Htr.	A-c	6.3	0.3	300	200	8.5	7.0	0.003
6SH7	Sharp-cut-off h.f. amplifier pentode	8BK	8–1	Htr.	A-c	6.3	0.3	300	150	8.5	7.0	0.003
6SJ7	Sharp-cut-off detector-amplifier pentode	8N	8–1	Htr.	A-c	6.3	0.3	300	125	Pentode connection		
								250	.....	Triode connection		
6SK7	Remote-cut-off r.f. amplifier pentode	8N	8–1	Htr.	A-c	6.3	0.3	300	125	6.0	7.0	0.003
6SV7	Diode r.f. pentode	7AZ	8–1	Htr.	A-c	6.3	0.30	300	150	6.5	6.0	0.004
6V6-GT	Beam power amplifier	7AC	9–11	Htr.	A-c	6.3	0.45	315	285	Single tube		
										2 tubes		

[a] Without external shield.
[b] Approximate.
[c] Zero signal.
[d] Per section.

Preferred Types of Vacuum Tubes—*(Continued)*

Type of service	Neg. grid volts	Screen volts	Screen milli-amp.	Plate volts	Plate milli-amp.	R_p, ohms	G_m, μmhos	μ factor	Load for rated output, ohms	Power output, watts
Class A amplifier	7.0	67.5	1.4	90	7.4	100,000[b]	1,575	...	8,000	0.270
Class A amplifier	7.0	67.5	1.5	67.5	7.2	100,000[b]	1,550	...	5,000	0.180
Class A amplifier	7.0	67.5	1.1	90	6.1	100,000[b]	1,425	...	8,000	0.235
Class A amplifier	7.0	67.5	1.2	67.5	6.0	100,000[b]	1,400	...	5,000	0.160
Class A amplifier	.....	300	2.5	300	10.0	1,000,000[b]	9,000	9,000		
Class A amplifier	Rk = 68Ω	100	4.2	250	11.0	1,500,000	4,400			
Class A amplifier	21.0	250	4.0[c]	315	25.5[c]	75,000[c]	2,100	.....	9,000	4.5
Class A amplifier	25.5	285	4.5[c,d]	285	27.5[c,d]	Peak grid to grid voltage = 51 volts			12,000[e]	10.5
Class A amplifier	14.0	250	5.0[c]	250	72.0[c]	22,500	6,000	.....	2,500	6.5
Class A amplifier	18.0	250	2.5[c]	350	54.0[c]	33,000	5,200	.....	4,200	10.8
Class A amplifier	17.5	270	11.0[c]	270	134.0[c]	23,500	5,700	.....	5,000	17.5
Class AB_1 amplifier	22.5[f]	270	5.0[c]	360	88.0[c]	.....	.....	.....	3,800	18.0
Class AB_2 amplifier	22.5[g]	270	5.0[c]	360	88.0[c]	.....	.....	.....	3,800	47.0
Class A amplifier	2.5	150	3.4	250	9.2	1,000,000[b]	4,000			
Class A amplifier	1.0	150	4.1	250	10.8	900,000[b]	4,900			
Class A amplifier	3.0	100	0.8	250	3.0	1,000,000[b]	1,650			
Class A amplifier	8.5	.....	.....	250	9.2	7,600	2,500	19		
Class A amplifier	3.0	100	2.6	250	9.2	800,000[b]	2,000			
Class A amplifier	1.0	150	2.8	250	7.5	800,000[b]	3,400			
Class A amplifier	13.0	225	2.2[c]	315	34.0[c]	77,000	3,750	.....	8,500	5.5
Class AB; amplifier	15.0[f]	250	5.0	250	70.0	60,000	3,750	.....	10,000[e]	10 0[i]

[c] Plate to plate.
[f] Grids never driven positive.
[g] Grids driven positive.
[i] Undistorted

Characteristics and Ratings of

Tube type	Classification by construction	Base connections (Fig. 1.)	Outline drawing (Fig. 2.)	Type cathode	Filament supply	Filament volts	Filament amp.	Max. plate volts	Max. screen volts	Capacitance $\mu\mu f$. Input	Output	Grid plate
12BA6	Remote-cut-off r.f. amplifier pentode	7CC	5–2	Htr.	A-c	12.6	0.15	300	125	5.5[a]	5.0[a]	0.0035[a]
12SG7	Semiremote-cut-off high-G_m amplifier pentode	8BK	8–1	Htr.	A-c	12.6	0.15	300	200	8.5	7.0	0.003
12SK7	Remote-cut-off r.f. amplifier pentode	8N	8–1	Htr.	A-c	12.6	0.15	300	125	6.0	7.0	0.003
35L6-GT	Beam power amplifier	7AC	9–11	Htr.	A-c	35.0	0.15	200	117	13.0	9.5	0.8
50B5	Beam power amplifier	7BZ	5–3	Htr.	A-c	50.0	0.15	117	117	13.0[a]	6.5[a]	0.50[a]
50L6-GT	Beam power amplifier	7AC	9–11	Htr.	A-c	50.0	0.15	200	117	.....	.....	.....

Multipurpose tubes

1R5	Pentagrid converter	7AT	5–2	Fil.	D-c	1.4	0.05	90	67.5	Osc. $I_g = 0.25$ through 0.1 megohm		
1S5	Sharp-cut-off diode pentode	6AU	5–2	Fil.	D-c	1.4	0.05	90	90	.....	.....	.....
6AT6	Duplex diode triode	7BT	5–2	Htr.	A-c	6.3	0.30	300	.....	2.3[a]	1.1[a]	2.1[a]
6AQ7-GT	Duplex diode triode	8CK	9–11	Htr.	A-c	6.3	0.30	250	.....	2.3[a]	1.5[a]	2.8[a]
6AR7-GT	Duplex diode triode	8CG	9–7	Htr.	A-c	6.3	0.30	300	.....	1.4[a]	1.0[a]	2.0[a]
6BE6	Pentagrid converter	7CH	5–2	Htr.	A-c	6.3	0.30	300	100	Osc. $I_g = 0.5$ ma. through 20,000 ohms		
6SA7[a]	Pentagrid converter	8R	8–1	Htr.	A-c	6.3	0.3	300	100	Osc. $I_g = 1.0$ ma. through 20,000 ohms		
6SC7	Twin-triode amplifier	8S	8–1	Htr.	A-c	6.3	0.3	250	.....	Each triode		
6SF7	Remote-cut-off amplifier diode pentode	7AZ	8–1	Htr.	A-c	6.3	0.3	300	100	5.5	6.0	0.004
6SL7-GT	Twin-triode amplifier	8BD	9–11	Htr.	A-c	6.3	0.3	250	.....	Each unit		

[a] Without external shield.

[b] Approximate.

Preferred Types of Vacuum Tubes—(*Continued*)

Type of service	Neg. grid volts	Screen volts	Screen milli-amp.	Plate volts	Plate milli-amp.	R_p, ohms	G_m, μmhos	μ factor	Load for rated output, ohms	Power output, watts
Class A amplifier	Rk = 68Ω	100	4.2	250	11.0	1,500,000	4,400			
Class A amplifier	2.5	150	3.4	250	9.2	1,000,000[b]	4,000			
Class A amplifier	3.0	100	2.6	250	9.2	800,000[b]	2,000			
Class A amplifier	8.0	110	2.0[b,c]	200	41.0[c]	40,000[b]	5,900	.....	4,500	3.3
Class A amplifier	7.5	110	4.0	110	49.0	14,000[b]	7,500	.....	2,500	1.9[c]
Class A amplifier	8.0	110	2.0[b,c]	200	50.0[c]	30,000[b]	9,500	.....	3,000	4.3
Converter	0.0	67.5	3.2	90	1.6	Conversion transconductance = 300				
Converter	0.0	67.5	3.2	67.5	1.4	Conversion transconductance = 280				
Converter	0.0	45	1.9	45	0.7	Conversion transconductance = 235				
Class A amplifier	0.0	67.5	0.4	67.5	1.6	600,000[b]	625			
Class A amplifier	3.0	.....	.....	250	1.0	58,000	1,200	70		
Class A amplifier	2.0	.....	.....	250	2.3	44,000	1,600	70		
Class A amplifier	2.0	.....	.....	250	1.3	66,500[b]	1,050	70		
Converter	1.5	100	7.1	250	3.0	1,000,000[b]	Conversion transconductance, 475			
Converter	2.0	100	8.5	250	3.5	1,000,000[b]	Conversion transconductance = 450			
Class A amplifier	2.0	.....	.....	250	2.0[c]	53,000[b]	1,325[b]	70		
Class A amplifier	1.0	100	3.3	250	12.4	700,000[b]	2,050			
Class A amplifier	2.0	.....	.....	250	2.3	44,000	1,600	70		

[c] Zero signal.

Characteristics and Ratings of

Tube type	Classification by construction	Base connections (Fig. 1).	Outline drawing (Fig. 2.)	Type cathode	Filament supply	Filament volts	Filament amp.	Max plate volts	Max. screen volts	Capacitance $\mu\mu$f.		
										Input	Output	Grid plate
6SN7-GT	Twin-triode amplifier	8BD	9–11	Htr.	A-c	6.3	0.6	300	.....	Each unit		
6SQ7	Duplex diode high-μ triode	8Q	8–1	Htr.	A-c	6.3	0.6	300	.....	3.2	3.0	1.6
6SR7	Duplex diode triode	8Q	8–1	Htr.	A-c	6.3	0.3	250	.....	3.6	2.8	2.4
6SV7	Diode r.f. pentode	7AZ	8–1	Htr.	A-c	6.3	0.30	300	150	6.5	6.0	0.004
12AT6	Duplex diode triode	7BT	5–2	Htr.	A-c	12.6	0.15	300	.....	2.3[a]	1.1[a]	2.1[a]
12BE6	Pentagrid converter	7CH	5–2	Htr.	A-c	12.6	0.15	300	100	Osc. $I_g = 0.5$ ma. through 20,000 ohms		
12SA7	Pentagrid converter	8R	8–1	Htr.	A-c	12.6	0.15	300	100	Osc. $I_g = 1.0$ ma. through 20,000 ohms		
12SQ7	Duplex diode high-μ triode	8Q	8–1	Htr.	A-c	12.6	0.15	300	.....	3.2	3.0	1.6

[a] Without external shield.

[b] Approximate.

Preferred Types of Vacuum Tubes—(*Continued*)

Type of service	Neg. grid volts	Screen volts	Screen milli-amp.	Plate volts	Plate milli-amp.	R_p, ohms	G_m, μmhos	μ factor	Load for rated output, ohms	Power output, watts
Class A amplifier	8.0	.....	.....	250	9.0	7,700	2,900	20		
Class A amplifier	2.0	.....	.....	250	0.9	91,000	1,100	100		
Class A amplifier	9.0	.....	.....	250	9 5	8,500	1,900	16	10,000	0.300
Class A amplifier	1.0	150	2.8	250	7.5	800,000[b]	3,400			
Class A amplifier	3.0	.....	.....	250	1.0	58,000	1,200	70		
Converter	1.5	100	7.1	250	3.0	1,000,000[b]	Conversion transconductance = 475			
Converter	2.0	100	8.5	250	3.5	1,000,000[b]	Conversion transconductance = 450			
Class A amplifier	.....	.....	.....	250	0.9	91,000	1,100	100		

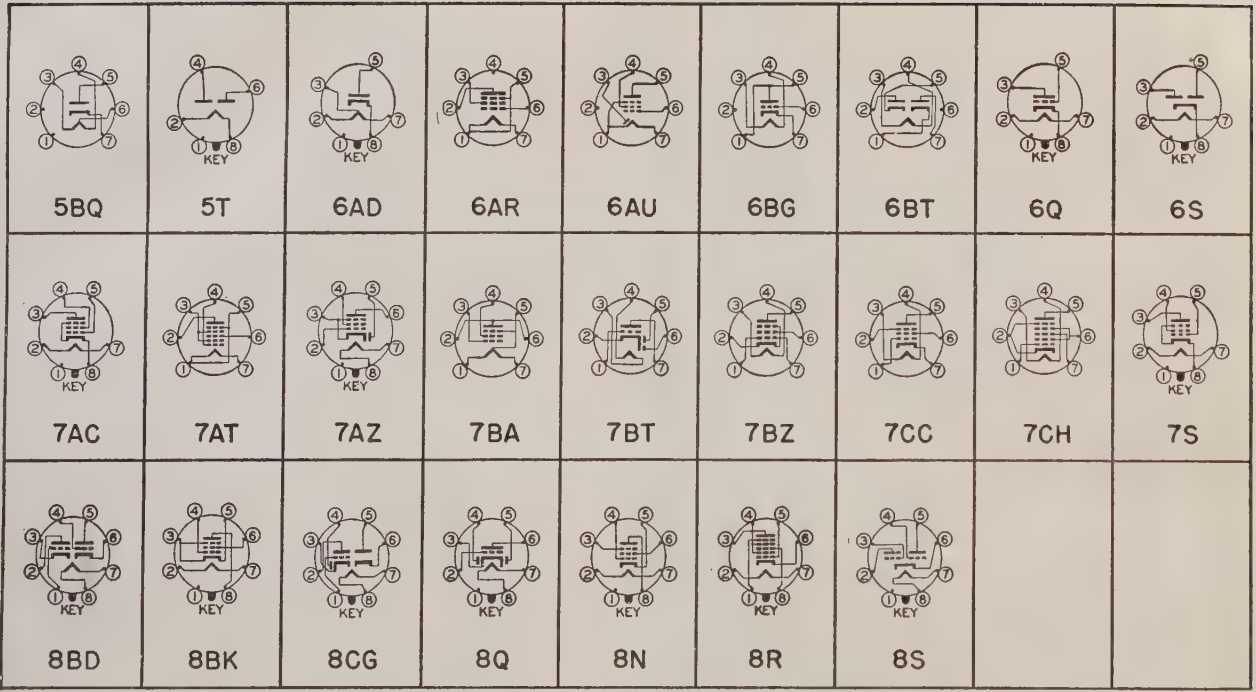


FIG. 1.—Tube-socket diagrams.

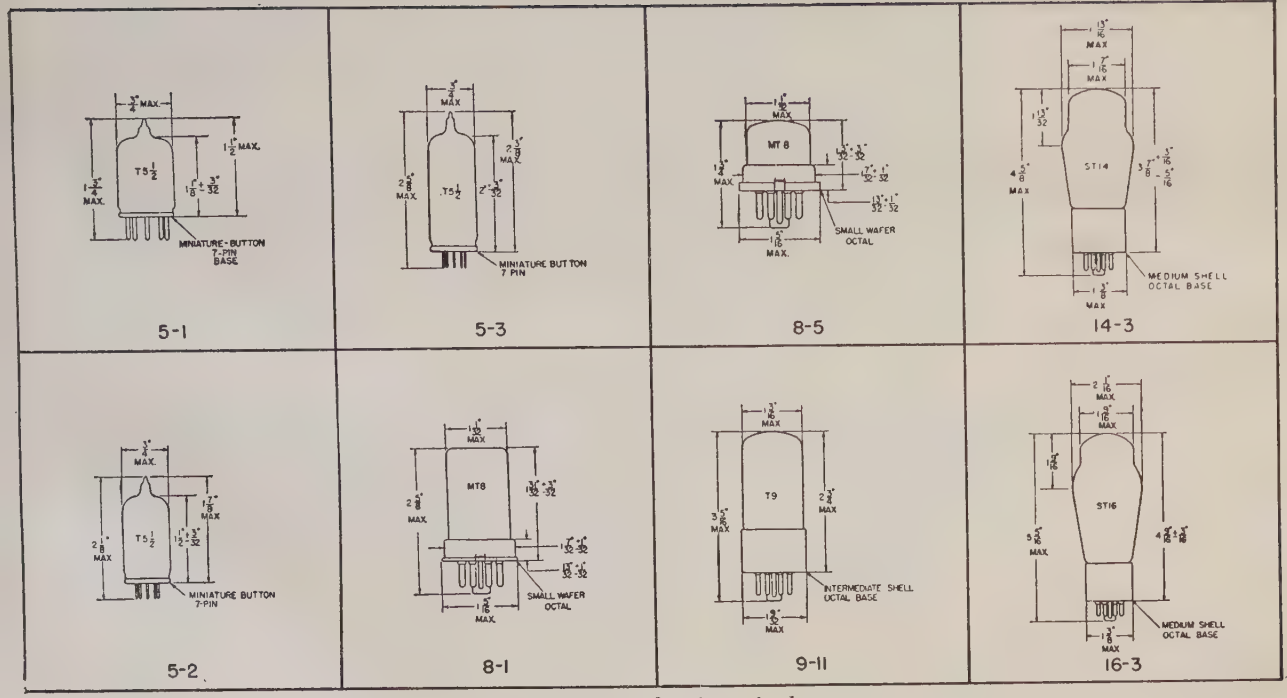


FIG. 2.—Outline drawings of tubes.

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